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The future of energy efficiency in post-COVID-19 era, 2nd edition

Edited by
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The future of energy efficiency in post-COVID-19 era, 2nd edition

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Assessing the Impact of the Digital Economy on Green Total Factor Energy Efficiency in the Post-COVID-19 Era

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Digital transformation in the energy sector is an essential tool for promoting the construction of a clean energy system in the post-COVID-19 era. Under the background of digital China strategy and sustainable energy transformation in the post-COVID-19 era, it is meaningful to investigate the relationship between the digital economy and green total factor energy efficiency (GTFEE) to better drive the development of the digital economy and improve GTFEE. For this purpose, this study estimates deeply the impact of the digital economy on GTFEE by applying ordinary least squares (OLS), panel vector autoregression (PVAR), panel threshold, and mediation effect models based on panel data of 30 Chinese provinces from 2006 to 2018. The statistical results indicate that digital economy is conducive to improving GTFEE. Digital economy can significantly contribute to GTFEE by improving economic growth level, urbanization level, R&D investment, and human capital. The most interesting finding was that there is also a non-linear relationship between digital economy and GTFEE. The effect of digital economy on GTFEE is shown to be first promoted and then inhibited as digital economy level continues to increase. Further, the positive impact of the digital economy on GTFEE is strengthened with increasing levels of economic growth, urbanization, R&D input, and human capital. Finally, A positive correlation was found between digital economy and GTFEE in the eastern and central regions, but insignificantly in other regions.

Keywords: digital economy, green total factor energy efficiency, impulse response analysis, mediation effect, threshold effect

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1 INTRODUCTION

The outbreak of COVID-19 in 2020 has a serious impact on the trade and economic pattern of countries all over the world (Iqbal et al., 2021), but it stimulated the overall acceleration of the digital economy (Razzaq et al., 2020; Ahmad et al., 2021; Yang et al., 2021). In the post-COVID-19 epidemic era, digital economy has become an important driving force to hedge the impact of the COVID-19 and promote economic stabilization and recovery (Irfan et al., 2021a). Meanwhile, with the continuous progress of information and communication technology, the entanglement of digital technology and the economy is getting increasingly deep, and digital economy is developing by leaps and bounds (Barefoot et al., 2018; Li Y. et al., 2021). As a more advanced and sustainable economic form, both the speedy evolution of the digital economy and its huge driving force for social

development are a pivotal role in promoting changes in the field of technology, accelerating industrial structure upgrading, and leading regional economic growth (Ciocoiu, 2011; Walsh, 2013; Sui and Rejeski, 2002).[1]. United Nations Conference on Trade and Development's Digital Economy Report 2019 states that digital economy is expected to account for 4.5–15.5% of world GDP, and about $3.7 trillion to $12.7 trillion.[2]. Meanwhile, digital economy scale is expanding year after year because of China's ongoing commitment to digital infrastructure. For example, according to the statistics in 2019, digital economy reached 35.8 trillion yuan, which accounted for 36.2% of GDP, rendering China's digital economy scale second in the world behind the United States (Zhang et al., 2021).[3]. The Chinese government has also attached considerable importance to digital economy development. For example, the 14th Five-Year Plan and Vision 2035 outline the need to accelerate digital economy development, which provides programmatic guidance for the development of the digital economy (Li Y. et al., 2021; Li Z. et al., 2021). With the development of digital economy, the production and consumption of traditional energy systems under the constraints of supply and demand balance will be changed (Yan et al., 2021), and energy can be controlled, managed, and traded across time and space (Akram et al., 2020; Elavarasan et al., 2021a; Chandio et al., 2021; Tanveer et al., 2021). Therefore, digital economy as a major driver of economic growth is likely to cause disruptions to exist economic processes, systems, and sectors, reshaping the current energy sector under the background of the post-COVID-19 era (Litvinenko, 2020).

Energy is not only an essential material basis for national development and security, but also the driving force behind the functioning of the national economic system (Hao et al., 2021a; Mukeshimana et al., 2020; Ahmad et al., 2021; Mohsin et al., 2021a; Sun et al., 2021a; Yang et al., 2021a; Khan et al., 2021; Mani et al., 2021; Razzaq et al., 2021). Because China is restructuring its economy and transforming its industries, the conflict between energy supply and demand has worsened (Rehman et al., 2021a; Wu et al., 2021a; Su et al., 2021). In particular, energy industry is more directly affected by COVID-19 (Irfan et al., 2021a; Irfan et al., 2021b), which brings significant changes and serious challenges to energy consumption and production and supply, mainly reflected in the negative growth of oil demand, less-than-expected natural gas demand, restrictions on coal transportation, and imbalance of power supply and demand. Meanwhile, in the post-COVID-19 era, along with the increasing internationalization of world energy market relations, the geopolitical instability of energy has increased (Elavarasan et al., 2021b). As the world's largest energy producer and consumer, China is facing structural overcapacity in traditional energy sources, multiple bottlenecks in renewable energy development, and overall inefficiencies in the energy system (Mohsin et al., 2021b; Li W. et al., 2021; Dagar et al., 2021; Ren et al., 2021). The economic development mode of high energy consumption and low output represented by resource-driven is unsustainable (Irfan et al., 2021c). Fossil energy is gradually limiting economic development, which improves green total factor energy efficiency (GTFEE) an attractive way to realize sustainable economic development in China in the post-COVID-19 era (Wang et al., 2020; Irfan et al., 2021e). Facing the increasingly serious problem of high pollution and high energy consumption and the contradiction between energy supply and demand, the Chinese government has taken a series of initiatives, including eliminating outdated industries, expanding low-pollution and low-energy industries, and curbing high-pollution and high-energy industries.

Besides, the Chinese government has even repeatedly emphasized promoting digital transformation in the energy sector, seizing the historical opportunity to integrate the digital technology revolution with the energy revolution, and striving to build a modern energy system that is clean, low-carbon, safe, and efficient with deep digital integration in post-COVID-19 era (Irfan et al., 2021f). Therefore, it is crucial to give full play to the role of digital technology in the energy sector and accelerate the construction of digital technology infrastructure to GTFEE. Some scholars point out that the digital economy can not only act on the technological innovation capacity of R&D subjects by affecting the rate of knowledge accumulation and the diffusion of technological spillover effects, but also have an impact on GTFEE by acting on clean production, pollutant emissions, and energy consumption per unit of output (Tleppayev, 2019; Vlasov et al., 2019). Simultaneously, the digital economy helps to improve the energy management system, which in turn has an important impact on GTFEE. Energy management is essentially a synergistic effect of material flow, energy flow, and information flow under the guidance of information flow. Digital economy's support to energy management systems effectively facilitates the improvement of the efficiency of material and energy flow utilization, the expansion of production efficiency and the reduction of energy cost. However, during the practical application process, there are still many challenges on how to accelerate the digital construction and regional energy transformation, especially how to drive GTFEE with digitalization which is still in the research exploration stage under the background of the post-COVID-19 era (Sui and Rejeski, 2002). So, does the digital economy promote or inhibit GTFEE? What are the mechanisms through which the digital economy affects GTFEE? Studying the relationship between digital economy and GTFEE not only improves the theoretical knowledge in related fields, but also helps to provide scientific and forward-looking empirical verification in the post-COVID-19 era for better guiding the development of the digital economy and improving GTFEE.

Our study differs from previous studies in the following aspects. First, the impact of the digital economy on GTFEE is systematically investigated. Secondly, digital economy index is constructed from the information development index, internet

[1]Digital economy is economic activity that uses digital knowledge and information as production factors, modern information network as carrier and information and communication technology as support to promote economic efficiency and structural optimization.

[2]See more detail: https://unctad.org/webflyer/digital-economy-report-2019

[3]See more detail: https://www.caict.ac.cn/kxyj/qwfb/bps/202007/t20200702_285535.htm

development index, and digital transaction development index. Furthermore, the transmission mechanism of digital economy on GTFEE is deeply inspected from the four perspectives of economic growth, urbanization, R&D investment, and human capital.

The following paper is organized as follows: *Literature Review* literature review is provided. *Mechanism Analysis* explores the influence mechanism of the digital economy on GTFEE. *Methodology and Data* gives the methodology and data. *Results and Discussion* contains the empirical analysis and discussion of the results. *Conclusions and Policy Implications* is the conclusions and policy implications.

2 LITERATURE REVIEW

2.1 Research on Digital Economy

Tapscott, an American scholar, introduced the concept of digital economy in 1996, which earlier elaborated the impact of networking on the economy and how to use new technologies to create new enterprises to strive for success in the era of the new economy (Tapscott, 1996). However, at present, there is not a unified conclusion on the definition of the digital economy in academic circles. The concept of the digital economy, in a narrow sense, has been condensed by some scholar's definitions into ICT, e-commerce, digital delivery services, software or digital data (Brynjolfsson and Kahin, 2002; Nosova et al., 2018; Chien et al., 2021a). In a broad sense, related studies suggest that the digital economy involves not only artificial intelligence, cloud computing, self-driving technologies, blockchain, but also the digitization of traditional technologies, telecommunications services, digital banking systems, agriculture, and mining, or manufacturing (Teece, 2018). Alternatively, the digital economy is considered as a new model driven by digital Technologies. Mesenbourg (2001) divides the digital economy into the production of ICT infrastructure and the use of ICT in other economic processes. Knickrehm et al. (2016) characterize digital economy from an output perspective after a comprehensive survey analyzing the size of the digital economy in 11 major countries around the world. They believe that more than 20% of global GDP is closely linked to the digital economy, which includes the output generated by hardware, software, digital intermediate products used in the production process, related digital technologies, and the employees who use these digital tools to do their jobs (Knickrehm et al. (2016).

A genuinely "digital economy" is defined as an economy in which a portion of economic output is derived exclusively or predominantly from digital technologies. Digital economy is a major driver of economic growth with far-reaching regional impacts on businesses, employment, and citizens (Brynjolfsson and Kahin, 2002; Ciocoiu, 2011). However, there are also opposing views that the digital economy may be detrimental to development and that digital technologies may exacerbate the premature deindustrialization of developing countries (Rodrik, 2016). Moreover, some scholars argue that in addition to e-commerce in the traditional sense, digital economy should also include information technology, the infrastructure of information technology, digital transmission in IT and other industries, and the sale of practical goods based on IT technology (Moulton, 2000; Kling and Lamb, 1999). In terms of measuring the digital economy, OECD has been improving the measurement framework of digital economy over time from a knowledge economy to information economy to internet economy and finally to digital economy. The United States National Bureau of Economic Analysis provides a framework for measuring the digital economy, including the foundation of the digital economy, digital media, and e-commerce (Barefoot et al., 2018). European Union, for its part, has constructed a digital economy and society index based on its relevant industries and infrastructure (Stavytskyy et al., 2019).

2.2 Research on Green Total Factor Energy Efficiency

GTFEE is the aggregate of economic and environmental benefits per unit of energy. To pursue the goal of energy conservation and emission reduction, investigating the influencing factors of GTFEE has been widely followed by policy makers and scholars. First of all, GTFEE is measured by two primary methods of single factor energy efficiency and total factor energy efficiency. Single-factor energy efficiency is mainly characterized by the ratio of economic output to energy input or energy input to economic output. Whereas, total factor energy efficiency focuses on energy and other factors of production utilization efficiency, which reveal the interrelationship between energy and economy, and has been commonly used by scholars in various countries (Yu and Zhang, 2019; Wu et al., 2021b; Zhu et al., 2019). Second, the impact factors of GTFEE have been investigated by most scholars. Some scholars argue that technological progress is one of the key factors affecting GTFEE. On the one hand, technological progress facilitates the improvement of GTFEE as it enables firms to produce the same output with less energy input (Fisher-Vanden et al., 2004; Crompton and Wu, 2005; Sun et al., 2021b; Chen et al., 2021). For example, Sun et al. (2021b) confirm that cross-border spillovers of technological innovation effect GTFEE and sectoral performance in other countries, subject to an examination of the effect of geographical distance. Chen et al. (2021) find a positive impact of technological innovation on GTFEE by designing a framework of sustainable development goals. Li and Lin (2018) reveal that a positive correlation between Hicks-neutral technological progress to energy efficiency, with technological catch-up playing an indirect role. Other scholars have found new evidence that technological progress, while reducing energy consumption and thus increasing energy efficiency, also facilitates the expansion of economic output size and reduces the unit cost of energy use, which may eventually cause energy savings from efficiency gains being partially offset by additional energy consumption from increased energy demand (Böhringer and Rivers, 2021; Bruns et al., 2021). The idea of the rebound effect was first proposed by (Khazzom, 1980) and has been theoretically analyzed and empirically tested by scholars since then (Binswanger, 2001; Du et al., 2021; Li, 2021). Lu et al. (2017)

examine the rebound effects of different energy types in China using a static computable general equilibrium model and observe that the rebound at the macro level is larger than that at the production level, with primary energy commodities showing a larger rebound effect than secondary energy commodities. Moreover, other influences on GTFEE from previous studies include industrial structure, international trade, institutional quality, level of economic development, human capital, energy consumption structure, and energy prices, etc (Alfalih and Hadj, 2021; Lin and Zhou, 2021; Tang et al., 2021; Yao et al., 2021). [Pan et al., 2020; Yao et al. (2021)], for example, empirically find that both OFDI and FDI significantly increase GTFEE. (Fisher-Vanden et al., 2006), in their study of data from medium and large-sized Chinese firms, suggest that changes in industrial structure are the main reason for the decrease in energy intensity. Xiong et al. (2019) applying a relaxed measure model that includes non-desired outputs to assess energy efficiency observed that industrial structure is a determinant of industrial energy efficiency (Edziah et al., 2021). Using the stochastic Frontier model and energy demand function confirmed that positive externalities of human capital can improve GTFEE.

2.3 Research on Digital Economy and GTFEE

The relationship between digital economy and GTFEE has been investigated relatively rarely by scholars, while most studies have been conducted from the perspectives of information industry, informatization, and integration of both, exploring the relationship between internet utilization, ICT, and GTFEE (Wu et al., 2021a; Murshed, 2020; Ren et al., 2021; Usman et al., 2021; Wang et al., 2021). Scholars have paid attention to the energy consumption effects of ICT since the early days of its development, but the relevant analysis mainly concentrates on the energy consumption effects of ICT. For example, Collard et al. (2005) show that the use of computer hardware and software in the French service sector has a significant effect on the intensity of electricity use. Berkhout and Hertin (2001) argue that in contrast to the productivity paradox, the intelligent production, supply chain restructuring, and material electronification brought about by ICT have all increased green total factor energy efficiency to some extent. Subsequently, scholars have conducted extensive empirical studies to validate the findings of Berkhout and Hertin (2001). For example, Soares et al. (2021) state that an integrated platform of information and communication technology (ICT) can help building managers save energy.

Subsequently, scholars have conducted extensive empirical studies to validate the findings of Berkhout and Hertin (2001). For example, Soares et al. (2021) state that an integrated platform of information and communication technology (ICT) can help building managers save energy. However, some scholars have come to a different conclusion through studies that there is a significant positive correlation between ICT and internet applications because of a "rebound effect." (Takase and Murota, 2004) confirm that investment in information technology increases energy consumption instead due to the income effect that emerged (Longo and York, 2015). also realize that ICT penetration shows a positive correlation with energy consumption, and therefore conclude that ICT does not inhibit the environment quality. In addition, while focusing on the energy consumption effects of ICT technologies, some scholars have begun to directly study the energy effects of the internet, but the conclusions reached are also controversial. Some studies have argued that the Internet enhances GTFEE (Lee, 2010; Muñiz and Cuervo, 2018; Li and Du, 2021). For example (Wu et al., 2021a), discover that in China Internet development affects GTFEE by reducing resource mismatch, promoting technological innovation, and facilitating industrial structure upgrading. Dawadi et al. (2020) confirm that the network infrastructure in Nepal helps to significantly reduce energy consumption and carbon footprint, thus improving energy efficiency. Li and Du (2021) obtained similar results based on macro- and micro-matched data and find that the Internet can significantly contribute to energy efficiency in firms. Vlasov et al. (2019) believe that the digital economy provides opportunities for energy efficiency improvement in the areas of energy infrastructure control and household services. However, some studies indicate that the relationship is not negative or that the internet has a negligible impact on green total factor energy efficiency. Murtishaw and Schipper, 2001, for example, argue that the reduction in energy consumption per unit of GDP in the United States in the mid-to late-1990s cannot be attributed to energy efficiency improvements brought about by the application of the Internet and information technology, but was achieved through changes in the structure of societal energy demand (Salahuddin et al., 2016).

In general, existing research theoretically suggests that information technology has a positive effect on social development. Indeed, data, analysis, and connectivity are spread across the energy sector, and digital energy systems can effectively contribute to energy efficiency improvements by accurately locating energy supply, transport, and use, and monitoring energy exploration, resource waste, and environmental pollution. However, it is still debatable whether the digital transformation in the energy sector has played a positive role so far in its development because technological developments are potentially disconnected from practice. Considering that there are few studies on the relationship between the digital economy and GTFEE in the existing literature, and there are limitations in the research methods. Therefore, this paper firstly adopts the mediating effect and threshold model to carefully test the influence of digital economy on GTFEE. Second, previous studies on the digital economy have mostly focused on its drivers, while exploring GTFEE often considers the influence of institutional factors and other factors on it, therefore, this study on the digital economy and GTFEE is a valuable complement to this one. Finally, it is more accurate to construct a digital economy index to measure the digital economy level of each provincial administrative region than to use a single indicator to measure the digital economy situation.

3 MECHANISM ANALYSIS

3.1 The Direct Impact of the Digital Economy on GTFEE

GTFEE demands that ecological losses be minimized on the basis of achieving energy efficiency improvements. Therefore, it is crucial to find the kinetic energy to realize GTFEE improvement. Digital economy plays an important role in both energy efficiency improvement and environmental pollution control. The development of the digital economy has given rise to new, more energy-efficient ways of production, transportation, communication and data processing, and the systematic use of digital technology applications also contributes to greater scope for energy savings (Kinelski, 2020). Specifically, some examples of macro-level benefits that increase green total factor energy efficiency include expanded telecommuting and videoconferencing and widespread adoption of electronic billing (Ren et al., 2021). On the one hand, telephony and videoconferencing reduce the frequency with which people travel to work or attend business meetings. The most obvious result is that fewer people will need to take transportation or use vehicles, which results in less energy consumption (Walsh, 2013). On the other hand, the number of people making frequent online purchases and paying bills electronically will increase, and the traditional way of shopping by car or transport will decrease. These same approaches will also reduce road congestion and fuel consumption, thereby improving GTFEE.

Digital technology also promotes product innovation and increases the technological content and added value of products, which in turn reduces energy consumption from a micro perspective (Vlasov et al., 2019). In addition, digital technology helps improve energy management systems. For example, enterprises use digital technology to establish their energy management system, which can significantly improve the labor productivity of the energy system by centralizing the monitoring of the energy system via the energy management system. Meanwhile, digital technology helps cut down information cost, storage cost, and management costs in the process of energy utilization of enterprises, thus reducing energy consumption and improving the energy efficiency of enterprises (Kinelski, 2020). The openness and sharing characteristics of the digital platform effectively reduce the information cost in the process of energy utilization of enterprises, including the purchase information search cost, selection cost, and risk avoidance, as well as reduce the waste of resources caused by information asymmetry during energy utilization (Savchenko and Borodina, 2020). Finally, through the digital platform, enterprises can keep abreast of the energy market situation, realize the effective docking of energy demand and energy market, minimize the energy inventory of enterprises, effectively reduce energy storage costs, and enhance GTFEE. Thus, it can be seen that digital economy can provide solutions for GTFEE improvement. Based on this, this study puts forward the following hypotheses:

Hypothesis 1: digital economy has a significant positive impact on GTFEE.

3.2 The Indirect Impact of the Digital Economy on GTFEE

Digital economy can positively influence GTFEE by facilitating economic growth. Given the exponential growth of global digitization and informatization, digital economy is increasingly emerging as a new engine for economic recovery and growth. The rapid development of the digital economy has facilitated the flow of goods, promoted consumption, and boosted investment, thus enabling the economy to flourish. Digital economy directly facilitates the interaction between firms and emerging technologies such as the Internet to enhance the effectiveness of information dissemination and avoid information asymmetry, thus positively influencing economic growth (Choi and Yi, 2009). According to (Czernich et al., 2011), digital economy can reverse the innovative activities in economic production and make its development more relevant. Booming economies empower governments to build infrastructure that is conducive to reducing information gathering costs, transaction costs, and increasing knowledge spillovers, thereby contributing to green total factor energy efficiency (Sun et al., 2021b). Moreover, sustained economic growth reduces the risk of energy firms and sectors coping with economic uncertainties, which also contributes to the growth of GTFEE (Vaka et al., 2020). Further, the digital economy needs to rely on a new generation of information technology industries based on the Internet of things, big data, mobile Internet, cloud computing, and so on (Bulturbayevich and Jurayevich, 2020). The rise of these industries will promote the development of producer services represented by information services, and at the same time give birth to more new economic growth points. In particular, these industries have characteristics such as high value-added and low energy consumption and pollution.

Digital economy can indirectly affect GTFEE by influencing the level of urbanization, which is conducive to the sustainable development of cities (Alizadeh et al., 2017). In terms of digital city construction, the digital economy structure needs to rely on the new generation of information technology industries, mainly the Internet of Things, big data, mobile Internet, and cloud computing, and the new material industries, mainly new energy materials and information materials, which are all technology-intensive and low energy consumption industries (Anttiroiko et al., 2020; Ivanenko et al., 2020). Meanwhile, a higher level of urbanization means better infrastructure construction. For example, the construction of cities supported by the digital economy has promoted the extension of the new energy sector to all aspects of life, such as the birth of new energy vehicles, which directly optimizes the energy consumption structure, and thus promotes the progress of energy technology (Luo et al., 2021). In addition, as the level of urbanization continues to rise, the scale of the energy market continues to expand. By using digital technology, enterprises and society can continuously, and dynamically monitor the demand pattern of the market in real-time to keep abreast of the market demand and realize flexible scheduling of

production resources such as capital, labor, and energy to continuously enhance GTFEE.

Digital economy can positively influence GTFEE by promoting R&D input. The most significant features of the new round of technological and industrial revolutions are the digitization, intelligence, platformization, and servitization of manufacturing (Teece, 2018). Among them, digitalization and intelligent development provide the possibility to solve the problems of high energy cost and difficult energy transition that other countries are generally facing at this stage (Li, 2021). Increasing input in R&D will promote technological progress, and the birth of new technologies means the possibility of new energy sectors and new business modes (Welfens, 2008). Digital technology, through its network effect, can have positive spillover effects on all sectors of the enterprise, which can promote the research, and development of energy utilization technology in the enterprise (Benghozi and Salvador, 2016). At the same time, the digital platform supported by digital technology can not only promote the coordinated development of industry-university-research but also provide a carrier for the research and development of enterprise energy utilization technology and achievement transformation. In this case, constant penetration and integration of digital technologies with resource utilization technologies and energy-saving technologies foster intelligent energy-saving technologies, making production equipment with automatic control can be improved. Ultimately, enterprises and other social actors can achieve organizational optimization of different processes and steps according to the dynamic production situation to improve GTFEE.

Digital economy can positively influence GTFEE through human capital. Modern economy is a "digital economy" in a broad sense, when digitalization is a part of almost all economic activities (Szeles and Simionescu, 2020). Digital technology has become closely related to people's lives, with smartphones, global information networks, and virtual reality being technologies that people are often exposed to. The aforementioned characteristics determine that society as a whole becomes heavily reliant on digital technologies (Sundararajan, 2017). Whether from the perspective of technology creation and development or the user role of new technologies, all of these technological changes involve changes at the human capital level (Grigorescu et al., 2021). Digital economy development has brought high levels of education and improved knowledge and skills of human capital (Nevado et al., 2020). Isman and Canan (2014) argue that the widespread use of digital tools in the digital society places new demands on the skills of individuals who use these tools, the so-called digital citizens. Through the use of digital technologies, the learning efficiency of the society's personnel is improved, the cost of communication between personnel is reduced, the efficiency of the use of human capital is increased, and a rich organizational experience is provided for the effective management of the energy sector or business, thus increasing the efficiency of energy use (Najarzadeh et al., 2014). For example, the proper design and implementation of digital technology strategies can make the management of energy subjects and the interoperability problems among organizational members effectively solved, and the uploading and distribution of information can be timely and accurate, which will undoubtedly promote the positive spillover of human capital (Andreev et al., 2021). Therefore, the digital economy improves human capital levels and maximizes the efficiency of human capital with the same investment of time and resources, and saves the management time and cost of human resources, which in turn improves GTFEE. Based on the above analysis, the following hypotheses are proposed:

Hypothesis 2: digital economy can indirectly promote GTFEE by affecting economic growth, urbanization, R&D investment, and human capital.

4 METHODOLOGY AND DATA

4.1 Methodology

4.1.1 Benchmark Regression Model

Fixed effects model fix individual differences at different time points, thus effectively excluding the effect of unobserved omitted variables on the dependent variable and the confounding effect on the relationship between the independent and dependent variables (Hedges, 1994). Fixed effects model is also able to address the estimation bias caused by missing variables to some extent (Wang et al., 2021). Therefore, following Gardiner et al. (2009), this study employs fixed-effects model to empirically examine the impact of digital economy on GTFEE using panel data from 30 provincial-level administrative regions in China from 2006 to 2018. The specific model setting is as follows.

$$ens_{it} = \alpha_0 + \beta_1 De_{it} + \beta_n X_{it} + \alpha_i + \nu_t + \varepsilon_{it} \quad (1)$$

where, ens_{it} denotes the GTFEE of province i in year t, De_{it} is the level of digital economy development in province i in year t. X_{it} are the control variables affecting green total factor energy efficiency, which are economic growth (gdp_{it}), urbanization ($urban_{it}$), R&D investment (rd_{it}), openness (fdi_{it}) and human capital (hum_{it}) respectively. α_i is the area effect associated with the province and ν_t is the time fixed effect. ε_{it} is a random perturbation term that varies over time. β_1 is the parameter to be estimated, which reflects the impact of the digital economy on GTFEE. Here, we assumption that ε_{it} is independently and identically distributed.

4.1.2 Influence Mechanism Test

Digital economy may affect GTFEE through economic growth, urbanization, R&D inputs, and human capital in the mechanistic analysis section. To verify whether the above variables are mediation variables, this study uses a medication effects model to conduct verification of the influencing mechanism of digital economy on the GTFEE. Mediation effect models can identify the process and mechanism of influence of independent variables on dependent variables (Rucker et al., 2011). Compared with similar studies that simply analyze the effect of independent variables on dependent variables, mediation analysis not only has methodological advantages but also often yields more in-depth results

(Yang et al., 2021a; Wang et al., 2021). Referring to Baron and Kenny (1986), the following model is constructed.

$$Y = \alpha X + \varepsilon_1 \tag{2}$$

$$M = \beta X + \varepsilon_2 \tag{3}$$

$$Y = \alpha' X + \gamma M + \varepsilon_3 \tag{4}$$

4.1.3 Heterogeneity Analysis

Considering that the impact of digital economy on GTFEE may have nonlinear time-varying characteristics, i.e., it will show different marginal effects with changes in factors such as digital economy, urbanization, R&D investment, human capital, and economic growth level. Therefore, this study uses the panel threshold model proposed by Hansen (1999) to test the nonlinear effects of the digital economy on GTFEE (Hansen, 1999). The advantage of the panel threshold model is to endogenously divide the sample into multiple intervals based on the estimated thresholds and evaluate the relationship between variables within each interval based on the data's characteristics. Moreover, because there may be multiple thresholds for the threshold variables, the following models are initially set as multiple threshold models. The specific model settings are as follows.

$$\begin{aligned} ens_{it} = {} & \beta_0 + \beta_1 X_{it} \times I\left(q_{it} \le C_1\right) + \beta_2 X_{it} \times I\left(C_1 < q_{it} \le C_2\right) + \cdots \\ & + \beta_3 X_{it} \times I\left(q_{it} > C_2\right) + \gamma_i Z_{it} + \nu_t + \lambda_i + u_{it} \end{aligned} \tag{5}$$

where i denotes a province and t denotes the t_{th} year. The core explanatory variable X_{it} is De_{it}, and the control variable is Z_{it}. q_{it} is the threshold variable, and this study uses De_{it}, gdp_{it}, $urban_{it}$, rd_{it}, and hum_{it} as the threshold C_1 and C_2 the threshold value. λ_i is the unobserved effect, ν is the time fixed effect term, and u_{it} denotes the random error term.

4.2 Variables Selection

4.2.1 Dependent Variable

Green total factor energy efficiency (ens): data envelopment analysis (DEA) shows significant advantages of non-parametric methods in dealing with the efficiency calculation of non-fixed data units and unspecified production functions. The traditional radial DEA method circumvents the effects of slack variables on efficiency and random errors on individual subjects. In contrast, the non-radial and non-angle slack-based models (SBM) can not only distinguish the efficiency size of effective decision units, but also solve the possible non-zero relaxation problem and undesired output problem in the calculation process. Therefore, using the non-radial and non-angular super-efficiency SBM model, this study cumulatively multiplies the global Malmquist-Luenberger index for each year based on the measurement of the GML index, i.e., the GTFEE values for each province with 2004 as the base period. The variables are selected as follows.

4.2.1.1 Input indicators

Input factors are divided into three indicators of capital, labor, and energy inputs. The capital stock is used to characterize capital inputs (the depreciation rate is chosen as 9.6%). Drawing on the method of Ren et al. (2021), the capital stock in the base period is expressed using the annual fixed asset investment amount multiplied by 10 times. Labor input is expressed using the number of employees at the end of the year. Energy input is chosen to be characterized by total energy consumption.

4.2.1.2 Output indicators

Energy inputs bring economic growth while also generating pollution and environmental problems. Therefore, under the framework of green development and environment-friendly constraints, the output indicators are selected to characterize the desired output and undesired output by two types of indicators: economic output and environmental cost, respectively. Among them, economic output is measured by total GDP, and environmental cost is expressed by industrial sulfur dioxide, wastewater, and soot emissions (we use the entropy method to derive the environmental pollution index as a proxy for environmental cost).

4.2.2 Core Explanatory Variable

Referring to Li Y. et al. (2021), we measure the digital economy (De) development level by the following approach. We decomposed the digital economy index into three dimensions: information development, internet development, and digital transaction development (see **Table 1**). To facilitate the comparison among the indicators, the threshold method in the linear dimensionless method is used to standardize the data. The specific measurements are as follows.

$$\begin{aligned} y_i &= \frac{x_i - max_{1 \le i \le n} x_i}{max_{1 \le i \le n} x_i - min_{1 \le i \le n} x_i} \times k + q \\ y_i &= \frac{x_i - min_{1 \le i \le n} x_i}{max_{1 \le i \le n} x_i - min_{1 \le i \le n} x_i} \times k + q \end{aligned} \tag{6}$$

among them, $max_{1 \le i \le n} x_i$ and $min_{1 \le i \le n} x_i$ denote the maximum and minimum values of the indicator, respectively. Eqs. **5**, **6** are used to standardize the cost-based indicators, and the benefit-based indicators, respectively. k and q are set by themselves according to the requirements of the transformed data distribution interval. Since the selected indicators are all benefit-based indicators, reference is made to the Information Technology Level Index (ILI) established by Zhang et al. (2017) and the Networked Readiness Index (NBI) constructed by Harvard University and the World Economic Forum. The calculation is as follows.

$$X_i = \frac{V_i - V_{min}}{V_{max} - V_{min}} \times 6 + 1 \tag{7}$$

where V_i is the primary data of the measured indicators, V_{max} is the maximum value of the primary data, and V_{min} is the minimum value of the primary data. After this data processing, all indicator values are between 1 and 7, with higher values indicating higher indicators. To make the indicators comparable across years, this study sets the measurement indicators with 2006 as the base period and standardizes them with the above formula. Meanwhile, to make the indexes of each province comparable among different statistical years and reflect the development of digital economy indexes, the data of years after the base period are processed as follows.

TABLE 1 | Digital economy index evaluation index system.

Objective level	First level indicator	Secondary indicator	Third level indicator	Indicator unit
Digital economy index	Informatization development index	Information foundation	Optical cable density	%
			Density of mobile phone base station	%
			Proportion of informatization employee	%
		Impact of informatization	Total telecom services	%
			Software business revenue	%
	Internet development indicator	Fixed end Internet foundation	Internet access port density	%
		Mobile Internet foundation	Mobile phone penetration	%
		Impact of fixed end Internet	Proportion of broadband Internet user	%
		Impact of mobile Internet	Proportion of mobile Internet user	%
	Digital transaction development indicator	Fundamentals of digital trading	Proportion of enterprise website	%
			Proportion of computers used by enterprise	%
			Proportion of e-commerce	%
		Impact of digital transactions	E-commerce sale	%
			Online retail sale	%

Note: The units of indicators are all "%", and the attributes of indicators are all positive.

$$X_{it} = \frac{V_{it} - V_{min0}}{V_{max0} - V_{min0}} \times 6 + 1 \tag{8}$$

where t represents the measurement year, V_{max0} and V_{min0} represent the maximum and minimum values of the original data in the base period year, respectively. After the above processing, the measures can be compared among different years. Meanwhile, the highest and lowest scores of indicators in non-base period years may be greater than 7 or less than 1, which can also reflect the development of digital economy measures over time. In terms of weight treatment, this study refers to the NBI index weight determination method for assigning weights. After determining the weights, the linear weighting method is applied to calculate the digital economy index (DE). The specific measurement formula is as follows.

$$DE_{it} = \sum_{j=1}^{15} X_{it} \times W_j \left(j = 1, 2, \cdots, 15\right) \tag{9}$$

where j denotes the standardized three-level indicator and W_j denotes the weight of the j_{th} three-level indicator with respect to the digital economy index.

4.2.3 Other Variables

To more precisely quantify the influence of the digital economy on GTFEE, the following variables are selected to control for unobservables. Economic growth (gdp). it is generally believed that economic growth induces an increase in energy consumption, which in turn has an impact on GTFEE (Rehman et al., 2021b). Following (Jalil and Feridun. 2014), this study uses regional GDP to measure economic growth and converts it to constant 2006 prices. Human capital (hum). An increase in human capital level is conducive to the cultivation of energy technology talents and accelerates the development of energy utilization technologies, which in turn has an impact on GTFEE (Edziah et al., 2021). Referring to Wu et al. (2021a), this study uses years of education per capita to measure human capital. R&D investment (rd). Continued R&D investment will enable the acquisition of new knowledge and enable effective improvement of production processes and energy structure, which in turn will have an impact on GTFEE (He et al., 2021). This study selects the ratio of R&D expenditure to GDP to characterize R&D investment. Openness (fdi). On the one hand, foreign enterprises with advanced technology can spread more advanced and green, and clean production technology to the importing country, thus improving GTFEE (Wang, 2017). On the other hand, foreign enterprises may also transfer pollution-intensive industries to the importing country where the environmental regime is relatively lenient, increasing energy use while causing increased pollution emissions and lowering GTFEE. Following (Yang et al., 2021b), this study uses the amount of foreign direct investment to represent external openness. Urbanization ($urban$). The rising urbanization level leads to an increase in energy consumption, which may inhibit GTFEE. In contrast, an increase in urbanization level implies the improvement of economic development level, which is conducive to the development of energy-saving technologies and enhances GTFEE (Lv et al., 2020). This study selects the proportion of the urban population to total population to indicate urbanization.

4.3 Data

The panel data of 30 provincial-level administrative regions of China (excluding Tibet, Hong Kong, Macao, and Taiwan) from 2006 to 2018 are selected for this study. Specifically, all original data were derived from China Statistical Yearbook, China City Statistical Yearbook, China Internet Development Status Statistical Report, China Science and Technology Statistical Yearbook, China Environmental Statistical Yearbook, National Bureau of Statistics, and local statistical websites. The definitions of the statistical variables are presented in **Table 2**.

5 RESULTS AND DISCUSSION

5.1 Direct Effect Analysis and Discuss

5.1.1 Baseline Regression Analysis and Discuss

To make the results more comparable, this study also introduces the least square method (OLS) and random

TABLE 2 | Description of sample statistics.

Variables	Obs	Mean	Std. Dev	Min	Max	Units
ens	390	0.0430	0.0194	0.0145	1.1097	—
De	390	0.1413	0.1531	0.0126	0.5368	—
gdp	390	18916.3800	16641.0600	543.3200	97277.7700	Billion (Yuan)
urban	390	54.1045	13.6356	27.4600	89.6000	%
fdi	390	187.1184	287.8266	1.1599	2440.4310	Billions (USD)
rd	390	1.4784	1.0777	0.2000	6.0643	%
hum	390	8.9656	0.9694	6.5940	12.5550	Year

TABLE 3 | Baseline regression results.

Variables	OLS	RE	FE	OLS	RE	FE
De	0.054***	0.050***	0.053**	0.038*	0.018***	0.017***
	(8.831)	(5.842)	(1.990)	(1.842)	(8.620)	(7.710)
gdp				0.001**	0.003*	0.013***
				(2.310)	(1.726)	(6.359)
urban				0.001***	0.001***	0.001***
				(3.964)	(6.839)	(10.674)
fdi				−0.000***	−0.000***	0.000
				(−5.239)	(−2.876)	(0.232)
rd				0.047***	0.055***	0.042***
				(8.483)	(9.566)	(8.830)
hum				0.004***	0.006***	0.006***
				(3.330)	(4.440)	(4.810)
_cons	0.034***	0.034***	0.050***	−0.290***	−0.364***	−0.332***
	(24.549)	(17.497)	(8.629)	(−8.914)	(−11.305)	(−12.693)
R-squared	0.1674	0.5944	0.1674	0.5171	0.3817	0.4142
N	390	390	390	390	390	390

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

effect (RE) model to analyze the impact of digital economy on GTFEE (See **Table 3**). **Table 3** provides that the effect of digital economy on GTFEE is significantly positive whether or not control variables are added. Hypothesis 1 is verified. The findings are similar to those obtained by Li Y. et al. (2021) and Li and Du (2021). Li and Du (2021) argue internet can significantly improve the energy efficiency of enterprises. Economic growth, urbanization level, R&D input, and human capital also contribute positively to GTFEE. The reason for this may be that digital economy strengthens the technological linkage and interaction among energy sectors, which promotes technological spillover in the energy processes (Wu et al., 2021a). Subsequently, the learning effect and demonstration effect increase the diffusion and dissemination of energy use technologies among economic individuals and the advancement of energy technologies, which in turn improve GTFEE. In addition, the digital economy promotes the development of energy technology institutes and R&D platforms that integrate industry, academia, and research, and collaborate on innovation, ultimately accelerating the sharing of research resources. By accelerating the flow of factors (hum, capital, etc.), energy technology progress is thereby promoted (Murshed, 2020; Ren et al., 2021). Finally, digital economy drives the concept of sharing information, knowledge, technology, and capital, etc. throughout society. Through the digital economy, the whole society will change its behavior towards energy-saving and low-carbon and raise awareness of systematic digital management of the whole energy process, thus improving green total energy efficiency.

5.1.2 Robustness Checks

Tables 4, **5** provide the robustness checks of the baseline regression model under two scenarios: replacing the core explanatory variables and removing the extreme values, respectively. We recalculate digital economy levels using the entropy method and introduce them into the benchmark regression model as the core independent variables for robustness testing. Also, we re-estimate the baseline regression results by using the method of removing the extreme values of 1%. We find that after replacing the core explanatory variables and removing the extreme values, the coefficient of digital economy on GTFEE is still significantly positive. Therefore, Our findings are robust.

5.1.3 Direct Shock Effect Analysis and Discuss

To better analyze the relationship between digital economy and GTFEE, this study adopts a panel vector autoregressive model (PVAR) to check the direct shock role of digital economy on

TABLE 4 | Robustness test results (replacing core variables).

Variables	OLS	RE	FE	OLS	RE	FE
De	0.053***	0.050***	0.043***	0.040**	0.015*	0.015*
	(8.890)	(5.928)	(19.313)	(2.025)	(1.885)	(1.810)
gdp				0.001**	0.004*	0.013***
				(2.315)	(1.837)	(6.325)
urban				0.000***	0.001***	0.001***
				(3.987)	(6.939)	(10.680)
fdi				−0.000***	−0.000***	0.000
				(−5.355)	(−2.987)	(0.205)
rd				0.047***	0.055***	0.042***
				(8.584)	(9.615)	(8.816)
hum				0.002	0.005***	0.005***
				(1.360)	(4.210)	(4.410)
_cons	0.034***	0.034***	0.050***	−0.292***	−0.365***	−0.332***
	(24.719)	(17.689)	(8.559)	(−9.038)	(−11.415)	(−12.690)
R-squared	0.1692	0.5997	0.1692	0.5199	0.3790	0.4150
N	390	390	390	390	390	390

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

TABLE 5 | Robustness test results (removing extreme values).

Variables	OLS	RE	FE	OLS	RE	FE
De	0.054***	0.051***	0.014***	0.045**	0.021***	0.029***
	(8.882)	(5.916)	(6.806)	(2.211)	(2.962)	(4.025)
gdp				0.000**	−0.000	−0.000***
				(2.390)	(−0.549)	(−2.629)
urban				0.001***	0.001***	0.002***
				(5.617)	(7.472)	(10.750)
fdi				−0.000***	−0.000***	−0.000*
				(−7.562)	(−4.958)	(−1.902)
rd				0.044***	0.053***	0.042***
				(7.785)	(8.814)	(8.471)
hum				0.001	0.007***	0.006***
				(0.900)	(4.805)	(5.084)
_cons	0.034***	0.034***	0.049***	−0.281***	−0.360***	−0.338***
	(24.378)	(17.371)	(8.299)	(−8.661)	(−10.750)	(−12.259)
R-squared	0.1690	0.5950	0.1690	0.5475	0.4048	0.4234
N	390	390	390	390	390	390

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

TABLE 6 | Smoothness tests for key variables.

Variables	Symbols	Data processing	LLC test	IPS test	ADF-Fisher test
Green total factor energy efficiency	*ens*	Original order	9.7248	8.3944	4.4364***
		P-value	(1.0000)	(1.0000)	(0.0000)
	Δens	First-order difference	−1.3331*	−2.2741**	6.7085***
		P-value	(0.0913)	(0.0115)	(0.0000)
Digital economy	*De*	Original order	−4.8954***	−4.4781***	8.3704***
		P-value	(0.0000)	(0.0000)	(0.0000)
	ΔDe	First-order difference	−14.5567***	−9.4142***	16.6257***
		P-value	(0.0000)	(0.0000)	(0.0000)

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

GTFEE. Before taking the PVAR model, the core variables need to be tested for smoothness (**Table 6**) (Charfeddine and Kahia, 2019). The LLC, IPS, and ADF-Fisher tests show that the first-order difference series of digital economy and GTFEE are smooth. **Table 7** shows the results of the lag period selection. the AIC, BIC, and HQIC information criteria suggest that lag order-2 was selected for the analysis of the results in this study.

TABLE 7 | Selecting lag period number.

lag period	AIC	BIC	HQIC
1	−13.2861	−12.4959	−12.9698
2	−13.8984	−12.9922*	−13.5345*
3	−13.9526*	−12.9084	−13.5318
4	−13.9406	−12.7292	−13.4509
5	−13.8757	−12.4566	−13.3003

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

Figure 1 illustrates that the impact of the digital economy on GTFEE shows a trend of rising and then falling after being hit by one standard deviation of the digital economy, which tends to be stable in the long term. The above results suggest that the digital economy is increasingly contributing to GTFEE. The costs of enterprises in the management, production and transaction segments are adjusted by the impact of the digital economy. Digital technology has been transformed from a simple auxiliary tool to a core management tool as companies use digital technology for communication, information acquisition and distribution, internal management and business services, and even more deeply, systematic digital tools for transforming various business processes. As the application of digital economy in management has significantly improved the efficiency and management of enterprises, including the marginal output of invested human capital increases, the analysis and processing of large amounts of data is more convenient, as well as the accuracy and timeliness of enterprises to obtain and transmit information can be improved, GTFEE is also improved (Li and Du, 2021).

Second, the application of the digital economy in the transformation of industrial production processes is specifically manifested in the transformation of the supply chain. Internalization of the industry is a part of the "production-sales-consumption" collaborative upgrade, and its transformation is driven by the downstream distribution and consumption side (Vlasov et al., 2019). The higher the degree of downstream internet online and data, the more it can force the upstream manufacturing chain to innovate. Under the influence of the role of flexible production, a rapid response is achieved in the supply chain. The resulting accelerated production, shorter production cycles, and more scientific production methods and inventory management effectively reduce the waste of resources and increased storage costs caused by stalled products on the market (Ciocoiu, 2011). In addition, from the specific aspects of production and operation, enterprises are increasingly active in the downstream integration with the digital economy to form innovative models, including online sales, mobile social marketing, prepaid deposits, personalization, and other marketing models (Hao et al., 2021b). As the digital economy has significantly contributed to the transformation of the supply chain from traditional centralized mass production to market-oriented on-demand manufacturing, personalized and flexible production, thus improving the efficiency of production equipment and promoting green total factor energy efficiency (Lele et al., 2021).

5.2 Influence Mechanism Test Analysis and Discuss

Table 8 indicates the statistical results with economic growth, urbanization, R&D investment, and human capital as mediation variables, respectively. When economic growth is used as the mediation variable, the coefficient of *De* passes the 1% significance test and the coefficient of gdp passes the 5% significance test, which suggests that the digital economy can enhance GTFEE by promoting economic growth. With the speedy evolution of the digital economy, the economic growth level has been significantly improved. Under the favorable economic environment, the government can provide sufficient funds for enterprise development as a way to encourage enterprises to carry out clean production, thus facilitating the transformation of enterprise production mode and improving GTFEE.

When urbanization is used as a mediating variable, the coefficients of both *De* and *urban* pass the 1% significance test, which indicates that the digital economy can contribute to GTFEE by promoting urbanization. The digital economy is increasing and the "smart city" construction derived from it is advancing, which represents the continuous improvement of information infrastructure construction (Kondrasheva and Aleksandrova, 2019). The construction of "smart cities" supported by the digital economy has promoted the continuous development of intelligent technologies and the extension of new energy fields to all aspects of life. For example, the birth of new energy vehicles in smart cities directly reduces pollution emissions, optimizes the energy

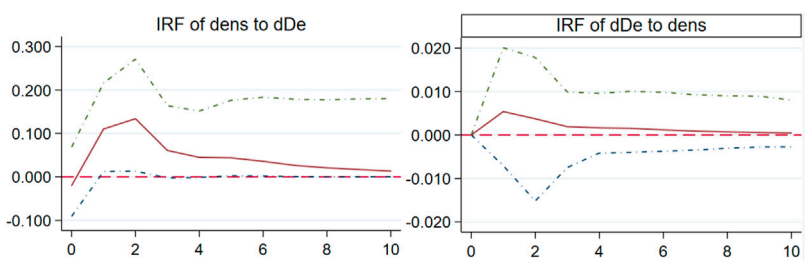

FIGURE 1 | Impulse response analysis diagram.

TABLE 8 | Mediation effect regression results.

Variables	M = Economic growth			M = Urbanization		M = R&D investment		M = Human capital	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
De	0.028***	0.005**	0.028***	23.303***	0.040***	3.326***	0.036***	0.009***	0.031***
	(6.141)	(2.089)	(6.334)	(8.229)	(9.069)	(12.444)	(9.252)	(4.156)	(6.724)
gdp	0.004**			0.004*	0.005***	0.010***	0.010***	0.000	0.036
	(2.016)			(1.849)	(2.616)	(4.512)	(4.516)	(0.032)	(0.241)
urban	0.001***	0.069	0.001***			0.138	0.001***	0.048***	0.000***
	(6.901)	(0.485)	(6.945)			(0.970)	(6.757)	(14.940)	(5.784)
fdi	−0.000**	7.653*	−0.000**	0.014***	0.000	0.001***	−0.000*	−0.000	−0.000**
	(−2.447)	(1.698)	(−2.471)	(10.556)	(0.932)	(4.661)	(−1.725)	(−0.791)	(−2.260)
rd	0.002***	0.004**	0.002***	0.006***	0.002***			0.277***	0.001*
	(3.189)	(2.071)	(3.243)	(2.856)	(2.879)			(7.638)	(1.941)
hum	0.004**	65.770	0.006***	7.892***	0.001	0.490***	0.063		
	(2.017)	(0.032)	(2.858)	(14.940)	(0.653)	(7.638)	(0.594)		
_cons	0.022***	0.077	0.022***	−22.496***	0.010	−3.389***	0.014**	5.753***	0.001
	(3.424)	(0.718)	(3.433)	(-5.486)	(1.505)	(−8.391)	(2.318)	(40.206)	(0.244)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.8258	0.8456	0.8500	0.8179	0.7436	0.8342	0.8212	0.8327	0.8291
N	390	390	390	390	390	390	390	390	390

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

consumption structure, and improves green total energy efficiency. The coefficients of *De* and *rd* pass the 1% significance test when R&D investment is used as the mediating variable, implying that the digital economy can promote R&D investment and thus improve green total factor energy efficiency. The development of the digital economy needs to have new technologies, while technological innovation cannot be separated from R&D investment. With the increase of R&D investment, the technology innovation level also increases (Chien et al., 2021b). The emergence of new technologies and new production models not only improves energy use efficiency from the production side but also reduces pollution emissions from the consumption side and realizes end-of-pipe management (Li and Du, 2021). The mediation effect significantly exists when human capital is used as the mediation variable, which is also similar to Edziah (2020) 's findings. As digital technologies continue to advance, there is an increasing need for human capital that is equipped with digital technologies (Grigorescu et al., 2021). Growing levels of human capital enable them to take full advantage of digital technologies and can enhance GTFEE through complementary organizational investments to ensure efficient use of digital technologies (Sousa and Rocha, 2019). Thus, digital economy can indirectly promote GTFEE by affecting economic growth, urbanization, R&D investment, and human capital, and hypothesis 2 is verified.

5.3 Heterogeneity Test Analysis and Discuss

5.3.1 Non-linear Effects Test Analysis and Discuss

Given the potential non-linear effects between the digital economy and GTFEE, this study uses the digital economy, economic growth, urbanization, R&D investment, and human capital as threshold variables, respectively, to investigate the effects of the digital economy on GTFEE under different threshold variables (See **Table 9**). This study finds that the triple threshold is significant when the digital economy is the threshold variable, while the double threshold is significant when economic growth, urbanization, R&D investment, and human capital are the threshold variables.

Then, after passing the threshold significance test, their respective corresponding threshold values and confidence intervals are calculated. **Table 10** reveals the threshold estimates and their confidence intervals at a 5% significance level and their corresponding threshold values when digital economy, economic growth, urbanization, R&D investment, and human capital are used as threshold variables.

Table 11 reveals that the effect of the digital economy on GTFEE is significantly positive when the threshold value is between 0.161 and 0.323, while it turns negative when the threshold value crosses 0.323 and negative but statistically insignificant after the threshold value exceeds 0.575. When economic growth is used as the threshold variable, the positive role of the digital economy on GTFEE increases significantly after crossing the threshold value. When urbanization is used as the threshold variable, the positive effect of the digital economy on the GTFEE also increases significantly with the increasing urbanization level. With R&D investment as the threshold variable, the digital economy has a positive but insignificant effect on GTFEE when the threshold value is lower than 2.190, and after crossing the threshold value of 2.190, the digital economy can significantly promote GTFEE. When human capital is the threshold variable, the digital economy plays a significant role in enhancing GTFEE, and such a role is strengthening with the increase of human capital investment.

It is not difficult to understand that firstly when the scale of digital economy is relatively low, the positive effect of digital economy as an emerging technology and infrastructure on GTFEE only starts to appear (Wu et al., 2021a). As digital technologies and infrastructures gradually spread, the

TABLE 9 | Threshold effect self-sampling test.

Core explanatory variable	Threshold variable	Model	F	P	BS	1%	5%	10%
Digital economy	Digital economy	Single threshold	12.536*	0.070	1000	17.359	13.699	11.329
		Double threshold	21.425***	0.000	1000	5.140	−0.988	−3.401
		Triple threshold	−3.811***	0.007	1000	−4.842	−9.449	−11.813
		Single threshold	26.322***	0.000	1000	22.624	16.057	13.860
	Economic growth	Double threshold	14.995***	0.010	1000	14.909	6.149	4.461
		Triple threshold	−44.147	0.637	1000	−20.082	−25.136	−27.608
		Single threshold	81.561***	0.000	1000	39.973	31.738	26.446
	Urbanization	Double threshold	50.167***	0.000	1000	−70.714	−80.768	−84.080
		Triple threshold	0.000	0.597	1000	0.000	0.000	0.000
		Single threshold	26.867**	0.043	1000	32.724	25.375	22.188
	R&D investment	Double threshold	8.253***	0.000	1000	−10.199	−21.677	−28.004
		Triple threshold	0.000	0.569	1000	0.000	0.000	0.000
		Single threshold	10.763*	0.053	1000	13.614	10.831	9.159
	Human capital	Double threshold	18.545*	0.100	1000	31.865	24.667	19.476
		Triple threshold	0.000	0.523	1000	0.000	0.000	0.000

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

TABLE 10 | Threshold estimates value and confidence intervals.

Core explanatory variable	Threshold variables	Model	Threshold value	95% Confidence interval
Digital economy	Digital economy	Triple threshold model	0.161	[0.132, 0.164]
			0.323	[0.132, 0.434]
			0.575	[0.180, 0.575]
	Economic growth	Double threshold model	13.692	[10.503, 33.897]
			18.457	[17.879, 18.595]
	Urbanization	Double threshold model	54.470	[53.000, 87.900]
			70.700	[70.700, 70.700]
	R&D input	Double threshold model	2.190	[0.460, 2.956]
			2.590	[0.400, 5.400]
	Human capital	Double threshold model	9.878	[8.811, 10.105]
			10.894	[10.894, 10.894]

technological revolution brought about by digital technologies induces an energy rebound effect (Takase and Murota, 2004). Coupled with a large amount of energy consumption and emissions brought by digital infrastructure, the digital economy has a dampening effect on the GTFEE. Therefore, the digital economy and GTFEE show an inverted "U-shaped" relationship. Secondly, economic growth, whether low, medium, or high, has a positive contribution to the impact of the digital economy on GTFEE. Economic prosperity provides a financial guarantee for the popularization of digital infrastructure and technology research and development, thus laying the economic foundation for GTFEE improvement (Choi and Yi, 2009). Thirdly, in the process of promoting urbanization and enhancing human capital, it will inevitably bring a large investment in infrastructure construction and a large inclination of educational resources. Meanwhile, urbanization and education investment provides a good environment for talent flow, gathering, and cultivation, forming a talent guarantee for digital technology, which in turn creates conditions for GTFEE enhancement. Finally, the stronger the intensity of its investment for R&D investment, the more potential for technological progress (Sun et al., 2021b). The emergence of new technologies will break the existing technological limitations and further improve the GTFEE.

5.3.2 Regional Heterogeneity Analysis and Discuss

Considering that digital economy development levels differ significantly among different regions in China, the samples are divided into eastern, central, and western regions to further examine the regional heterogeneity of digital economy on GTFEE (see **Table 12**). The results, as shown in **Table 11**, indicate that the coefficients of *east_De* and *midele_De* are significantly positive at the 1% level, indicating that the digital economy development significantly contributes to GTFEE in the eastern and central regions. However, the coefficient of *west_De* in the central region is smaller than that in the eastern region, indicating that the digital economy positively promotes GTFEE in the eastern region is higher than that in the central region. The impact of digital economy on GTFEE in the western region is positive but not statistically significant. The possible reason is that the digital base in the eastern region is better than that in the central and

TABLE 11 | Threshold regression results for core explanatory variables.

Variables	*Regime* = Digital economy	*Regime* = Economic growth	*Regime* = Urbanization	*Regime* = R&D input	*Regime* = Human capital
gdp	0.003	0.022***	0.002	0.006***	0.002
	(1.166)	(3.433)	(1.177)	(2.858)	(0.975)
urban	0.0011***	0.0011***	0.0013***	0.00117***	0.000969***
	(6.89)	(7.09)	(7.72)	(7.76)	(6.25)
hum	0.0077***	0.0077***	0.0064***	0.00487***	0.00565***
	(4.27)	(4.37)	(3.88)	(2.80)	(3.03)
fdi	−0.0001***	−0.0000***	−0.0001***	−0.0001**	−0.0025
	(−4.11)	(−4.76)	(−4.01)	(−2.21)	(−0.168)
rd	0.0038	0.0047*	0.0011	0.00203	0.00890***
	(1.37)	(1.74)	(0.43)	(0.85)	(3.57)
$De\cdot(Regime \le C_1)$	0.0470***	0.0061	0.0330***	0.0185	0.0136***
	(21.229)	(0.36)	(15.393)	(1.44)	(7.51)
$De\cdot(C_1<Regime \le C_2)$	0.0121***	0.0276*	0.038***	0.0128***	0.0143***
	(5.639)	(1.76)	(17.493)	(5.88)	7.01
$De\cdot(C_2<Regime \le C_3)$	−0.0759**	0.0330***	0.045***	0.0167***	0.0160***
	(-2.58)	(15.206)	(20.565)	(7.66)	(7.46)
$De\cdot (Regime > C_3)$	−0.0137	—	—	—	—
	(−1.13)	—	—	—	—
_cons	−0.0895***	−0.0810***	−0.0634***	−0.0606***	−0.0671***
	(−6.94)	(−6.45)	(−5.34)	(−4.87)	(−5.42)
R-squared	0.494	0.482	0.391	0.417	0.397
N	390	390	390	390	390

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01.*

TABLE 12 | Regional heterogeneity regression results.

Variables	Eastern Eegion	Central region	Western region
gdp	0.009***	0.000***	0.000
	(4.016)	(2.662)	(1.396)
urban	0.000***	0.001***	0.001***
	(5.480)	(7.946)	(9.501)
fdi	−0.000***	−0.000***	−0.000***
	(−2.776)	(−4.693)	(−4.356)
rd	0.003***	0.004***	0.005***
	(3.732)	(7.012)	(7.260)
hum	0.022***	0.019***	0.020***
	(10.722)	(8.961)	(9.201)
east_De	0.027***		
	(7.344)		
midele_De		0.014***	
		(6.533)	
west_De			0.001
			(0.058)
_cons	0.023***	0.015**	0.023***
	(3.678)	(2.212)	(3.294)
R-squared	0.8443	0.8334	0.8217
N	390	390	390

*Note: () indicates T-value or Z-value; *p < 0.1, **p < 0.05, ***p < 0.01. east_De", "midele_De", and "west_De" represent the digital economy of the eastern region, the digital economy of the central region, and the digital economy of the western region, respectively.*

western regions, and the digital economy is developing faster. There is a significant "digital divide" between the eastern, central, and western regions. Therefore, the digital infrastructure in the western region is more backward, which makes the digital economy cannot play a significant role in promoting GTFEE.

6 CONCLUSIONS AND POLICY IMPLICATIONS

This study constructs the digital economy index measurement system from three dimensions: information development, internet development, and digital transaction development, and calculates the digital economy index through a linear weighting method. Next, the direct effect of digital economy on GTFEE is empirically examined, and the influence mechanism of the digital economy on GTFEE is explored by using economic growth, urbanization, R&D investment and human capital as mediation variables. Finally, the non-linear effects of digital economy on GTFEE are separately investigated using economic growth, urbanization, R&D investment, and human capital as threshold variables, respectively, and then the sample is divided into different (eastern, central, and western) regions to reveal the regional heterogeneity of the relationship between the two. The major findings of the study are as follows.

Baseline regression results reveal that the digital economy has a significant positive impact on GTFEE. Economic growth, urbanization level, R&D investment, and human capital also contribute positively to GTFEE. Robustness checks such as replacing the core explanatory variables and removing extreme values are performed to ensure that the above results are still robust. PVAR model also indicates that as the digital economy continues to develop, it has an increasingly positive contribution to GTFEE. Digital economy can positively contribute to the GTFEE by improving economic growth level, urbanization level, R&D input level, and human capital. Finally, when the digital economy is used as the threshold variable, with the continuously increasing digital economy level, the digital economy shows a promoting and then inhibiting effect on

GTFEE. When economic growth, urbanization level, R&D investment, and human capital are adopted as threshold variables, generally the digital economy has a positive effect on GTFEE, of which this positive effect gradually strengthens with higher threshold values. Moreover, regional heterogeneity is found between the digital economy and GTFEE, with a significant positive effect of the digital economy on GTFEE in the eastern and central regions, while this effect is not statistically significant in the western region. Based on the above statistical results, the following implications were obtained from this study.

1) Strengthening digital economy development and steadily promoting internet infrastructure construction. In this process, the differences in digital economy development between the eastern, central, and western regions should be taken into account, and the support for the digital industry in the western region should be continuously deepened. The digital economy includes information technology, the internet, and digital transactions. Therefore, policy makers should effectively utilize the resource integration capability of the digital economy and accelerate the implementation of the "Internet+" strategy through the function of the Internet as public infrastructure. Policy makers should tailor their policies to local conditions based on the regional difference of the digital economy to better utilize the positive role of the digital economy on GTFEE.

2) Policy makers should set step-by-step energy saving and low carbon emission reduction targets to control emissions. In addition, the development and utilization of new energy sources such as green clean energy and renewable energy should be encouraged to optimize the energy consumption structure and promote the improvement of GTFEE (Irfan et al., 2020; Irfan et al., 2021g). Meanwhile, policy makers need to deeply expand the degree of digital utilization by using the attributes of digital technology facilities to connect everything to achieve a flexible and integrated automated energy management system and enhance GTFEE.

3) Policy makers should improve the mechanism for transforming research results, fully increase the investment in clean energy R&D to continuously promote scientific and technological progress, and reduce the ineffectiveness of innovation results, which ultimately improves the transformation rate of research achievements. Moreover, policymakers need to strengthen the cultivation of digital talents. There is an urgent need for composite professional talents who are both knowledgeable in energy economics and digital technology. Policymakers also need to work with universities and research institutes to develop digital talent training programs, which in turn realize a positive spillover to GTFEE.

Lastly, although this study thoroughly examines and discusses the relationship between the digital economy and GTFEE, some research limitations deserve to be further supplemented in the future. There may be a spatial nexus between GTFEE and the digital economy in each province, which may be an interesting study. However, this is beyond the scope of this study, so we suggest that it be carried out in future studies. There is similar evidence of a significant spatial correlation between energy efficiency and information and communication technologies across Chinese provinces (Hao et al., 2021b). Therefore, an investigation of the spatial linkages between the digital economy and GTFEE is very beneficial and promising for policymakers and scholars.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

SZ: Conceptualization, Methodology, Formal analysis, Writing—original draft, review and editing. XM: Conceptualization, Methodology, Supervision, writing—review and editing. SZ: Data and literature collection, preliminary analysis and writing. CQ: Visualization, Writing—review and editing, Project administration.

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Financial Consideration of Energy and Environmental Nexus with Energy Poverty: Promoting Financial Development in G7 Economies

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Energy and environmental concepts have been extensively studied in the past. However, these studies often lacked integrated analysis of energy, monetary, public, and ecological aspects to assess energy and environmental issues. This article provides analyzation of the G7 nations' qualitative, social, cultural, and health achievement in the energy poverty indexes. These include the energy economics and climate change of energy poverty, by using DEA like a composite indicator. The G7 countries' combined energy consumption is equal to 34% of the world's total, whereas the GDP is 50% of the global total. As a result, this article develops a comprehensive series of energy, financial, societal, and environmental indicators that are up to date. Such indicators are utilized to assess energy financial, societal, and EPI using a mathematical composite indicator. Canada has the greatest EPII score, indicating that it can deal better than the other G7 countries with energy independence, productivity expansion, and social impact, and France's and Italy's the second tier. While Japan has a 0.50 EPI grade and the United States will have the lowest, the G7 countries are growing faster. Finally, we propose a policy framework for enhancing the research area. The energy, societal, and EPI were created by combining these elements. In terms of energy independence, economic growth, and sustainability practices, Canada beats the other G7 countries according to the data. France and Italy are in the 2nd and 3rd places, respectively. Despite having a higher level of economic development than the G7 countries, Japan has a 0.50 Environmental Performance Index rating, whereas the United States has a minimum average Environmental Performance Index rating. Finally, in order to improve the study's subject, we propose a policy framework.

Keywords: energy finance, financial indicator, ecological perspective, climate change, energy poverty

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INTRODUCTION

Energy consumption has become the dominant drivers of financial development throughout the last century, allowing millions of citizens to climb out of poverty (Al-mulali, 2011; He et al., 2010). Due to its simple accessibility and unregulated use, energy has also been recognized to have a role in associated environmental challenges. The World Energy Council (WEC) annually produced a report utilizing an energy syllogism (Chen et al., 2019) to measure the performance of energy, commercial,

monetary, and environmental performance (World Energy Council and Oliver Wyman, 2018). The criteria for evaluating trilemma competency assessments are calculated in this study. The ETI is a statistical method that assesses the performance of the region's government and corporate leaders. It focuses on the regions where financial growth is critical (Anser et al., 2020f; Anser et al., 2020d).

The ETI is found to be the ideal way to rate countries based on their ability to build an acceptable, reliable, and cost-effective energy infrastructure (Aslan et al., 2018). It is determined by analyzing the ETI study's three high-performing elements. Three contradicting assessments of the trilemma index are assessed using a secure, logical, and generally achievable energy strategy (Radovanovi et al., 2017). This research noted the optimum slack in greenhouse gas emission for each nation using the factor greenhouse gases emission per capita, indicating that every nation may reduce emissions if they meet the standard. If the attained level meets the standards, every nation can eliminate about 90% of greenhouse gas emissions, meaning that many nations in the group have weak environmental performance (Zhe et al., 2016). These nations, on the other hand, have a huge opportunity to reduce GHG emissions. Since both factors have comparable properties, the erroneous output slack and beneficial inputs slack minimization can be optimized through organizational attempts. Ireland and Turkey, on the other hand, have stronger environmental performance because of higher GDP development, whereas the remaining nations have identical GDP development characteristics. Due to higher greenhouse gas emissions, worse energy efficiency, poorest renewable metrics, and GDP development, this research reveals that none of the area's states can be used as a model for environmental performance. Furthermore, to classify the nations, a relevant comparison can be made (Chandio et al., 2020; Baloch et al., 2020; Iram et al., 2020b).

Recent research has sought to quantify environmental efficiency using various energy ways as input variables, with pollutants or some other environmental effect serving as an undesirable output. For instance, A. Charnes et al. (1978), Abraham Charnes et al. (1978) used the DEA method to calculate this link, while Boyd and Färe (1984) applied the CCR framework, and Banker et al. (2000), Banker et al. (1984) proposed the BCC framework. Kong and Tongzon (2006) proposed an SBM that accepted output and input as slack owing to angles and radial selection, while Shephard (1978) recommended a distance function method for this objective. This was, therefore still unable to remedy the efficiency issue, which resulted in an unsatisfactory output. Charnes et al. (1994) devised a Malmquist index to solve this problem (M). Then Solow (1957) introduced a DDF that used the DEA approach to create the ML. The TFP score and measured environmental efficiency by using pollutant emission as a function of undesired output. Du et al. (2018) proposed structure Luenberger (L) as a producing creative index for productivity measures.

The energy economic and environmental concerns linked with energy poverty: social development linkage from the G7 countries is assessed in this study. This research will look into the contribution of energy financial and ecological advancement, as well as an effective managerial system for improving energy efficiency and reducing concentration, as just a manner forward toward emerging economies that are struggling to minimize the manufacturing costs by improving energy efficiency. The DEA technique was used to find the solution for improving energy efficiency in emerging economies, with the help of nations that had implemented improvements. It is one of the first empirical projects of its sort, involving power sector improvements to enhance energy efficiency in the longer term.

DATA AND METHODOLOGY

System of Indicators

The most crucial step in creating a meaningful and comprehensive energy, financial, and Environmental Performance Index is to create indicators. If metrics are gathered and examined properly, they might impart valuable information about energy, financial, and environmental issues. Additionally, these indicators deliver practical tools for policymakers to assess, analyze, and compare different countries' trends (Nardo et al., 2005). The construction of indicators has been divided into four categories including energy, economic, environment, and social indicators (Asif et al., 2020; Sarker et al., 2020; Iram et al., 2020a; Tehreem et al., 2020). Environmental performance is directly associated with energy since this sector is the major contributor to environmental degradation. The creation of indicators is the most important stage in constructing a useful and complete energy, economic, and Environmental Performance Index. If indicators are correctly collected and analyzed, they can provide meaningful information on energy, economic, and environmental challenges.

Energy Self-Sufficiency

The energy self-sufficiency ratio translates a country's capability to meet its national energy demand (Yao and Chang, 2014; Vera and Langlois, 2007). Energy self-sufficiency is a benefit-type statistic, meaning that the higher the number, the better; the mathematical formula is presented in **Equation 1**:

$$E_{suf} = \sum_{j=1}^{n} E_j w_j, \tag{1}$$

where E_j represents the energy self-sufficiency ratio of energy, defined in **Eq. 2**, and w is the fossil energy portion j.

$$E_j = \frac{E_{con} + (E_{exp} - E_{imp})}{E_{con}} \times 100\%, \tag{2}$$

where E_{con}, E_{exp}, and E_{imp} are the energy consumption, export, and imports of the fossil fuel j (Lombardi and Schwabe, 2017; Kemmler and Spreng, 2007).

Energy Dependency

It is a noteworthy fact that the high-energy dependency intrinsically generates high energy security threats (Patlitzianas et al., 2008; Turton and Barreto, 2006; Vera and Langlois, 2007). Countries dependent on imported energy are considered energy-insecure and climate-vulnerable since their economy is strongly dependent on

price fluctuations and the economic growth may weaken due to discontinuation in the energy market (Löschel et al., 2010; Greene, 2010).

$$Energy\,dependence = \frac{TPE_{con.} - TPE_{prd.}}{TPE_{con.}}, \quad (3)$$

where $TPE_{con.}$ is the total primary energy consumption and $TPE_{prd.}$ is the total primary energy production.

Diversification Index of Energy Dependency

The diversification index of energy dependency helps diversify the energy imports, and its values mean that the country is capable of diversifying their resources (Tapia et al., 2016; APERC, 2007; X. Wang et al., 2018). Country risk factors have been added to the diversification index of energy dependency as is shown in **Eq. 4**:

$$\mathrm{DIVI} = \mathrm{HHI} - \mathrm{PE} \times \mathrm{DEP_i} = \mathrm{DEP_i} \sum_{i=1}^{N} \mathrm{W_{ij}^2} \times \frac{1}{\mathrm{PE}} \times \mathrm{CR_i}\,, \quad (4)$$

where DIVI is the diversification index, $\mathrm{W_{IJ}} = \frac{\mathrm{X_{ij}}}{\sum \mathrm{X_{ij}}}$-$\mathrm{X_{ij}}$ is the percentage of energy suppliers j in the country's overall energy importation i, DEP is energy dependency on energy suppliers, W denotes the Herfindahl–Hirschman Index (HHI), P.E. is potential exports, and CR is the country's risk calculated by International Country Risk Guide (ICRG). Various researchers used the Shannon–Wiener index for this indicator (Shannon, 1948).

Energy Consumption

Energy consumption is considered a suitable indicator for measuring sufficient energy supply for human welfare (Cohen et al., 2011). Energy consumption is influenced by financial growth, population, energy structure, technological progress, industrial structure, urbanization, and industrialization level (Yousaf et al., 2020; Tehreem et al., 2020; Wasif Rasheed and Anser, 2017; Xu et al., 2020). Economists' groups encourage increasing energy consumption, while environmentalists discourage higher energy consumption, mediate between these two lobbies, reduce energy consumption, and do not negatively affect the economy; the latest energy policies strongly bet on energy efficiency (Martinez and Ebenhack, 2008). Countries at different economic development stages are considerably intended toward different energy sources, while energy consumption is also considered as mutually agreed consensus considering a cost-type indicator (Cohen et al., 2011; Sovacool and Mukherjee, 2011; Ang et al., 2015).

Carbon Emission Index

The following equation can be used to calculate the carbon emission index for every unit of energy used:

$$\mathrm{CE_{CO2}} = \mathrm{CO_{emi}}/\mathrm{E_{Con}}, \quad (5)$$

where $\mathrm{CE_{CO2}}$ is the amount of carbon dioxide emitted per unit of energy consumed (H. Wang et al., 2018), $\mathrm{C_{emi}}$ is $\mathrm{CO_2}$ emission, and $\mathrm{E_{Con}}$ is the total energy consumption.

Carbon Emission Intensity

CO2 emissions are mostly released by the energy industry [xx]. The fuel usage (Yuan et al., 2008; Filipović et al., 2015) can be calculated as given in **Equation (6)**:

$$\mathrm{CE_{ity}} = \mathrm{C_{emi}}/\mathrm{GDP}. \quad (6)$$

Renewable Energy Sources

The sustainable energy proportion of total power generation in the national energy mix is used to calculate the RES indicator (Muneer et al., 2007). The main benefits of RES are linked to the environment and energy independence, but on the other side, they create many issues in terms of energy management due to their non-predictability. RES increases the sufficient supplies of green energy insignificant problem due to increasing concerns of dependency on imported energy supplies (Verbruggen, 2008; Apergis and Payne, 2010). In fact, RES ensures and enhances the diversification of energy sources. By using local energy production, it enhances energy efficiency (Lund and Mathiesen, 2009; Wolde-Rufael and Menyah, 2010; Scarlat et al., 2015). It is regarded as a kind of utility indication as follows:

$$\text{Renewable share} = \frac{\text{Renewable electricty generation}}{\text{Total electricty generation}}. \quad (7)$$

Gross Domestic Product per Capita

GDP per capita is a standard indicator to measure economic growth. Despite many controversies, it is still deemed necessary for assessing economic prosperity and citizens' well-being (Lambiri et al., 2007; Konstantinaviciute and Bobinaite, 2015). GDP per capita is considered a benefit-type indicator.

GDP Productivity

GDP productivity is associated with the energy and economy relationship (Wang, 2011; Fiorito, 2013) as follows:

$$GDPProductivity = \frac{GDP}{EnergyProduction}. \quad (8)$$

Human Development Index Score

The social indicators can be investigated by the measurement of the well-known Human Development Index (HDI). The HDI guarantees that the final requirements for assessing a country's social and economic progress are attained. Human Development Index represents differentiate national policies' choices, having two countries with the same GNI per capita come up but different human development outcomes. The HDI took into account social factors such as a lifetime of happiness, education, and a good quality of living (Liu et al., 2020; Lin et al., 2020; Jun et al., 2020). The HDI is the geometric aggregation of normalized social indicators. The HDI is a comprehensive representation of social elements of human development, even though it does not cover human security, poverty, and endowment (Pasqualetti and Sovacool, 2012; Kemmler and Spreng, 2007).

Ratio of Forest Area

The ratio of forestry indicator is significant to measure the environmental condition and environmental degradation, and relatively it is easy to calculate. Consequently, the United Nations included this indicator to assess and monitor the performance of MDG (Radovanović and Filipović, 2015; Hughes, 2009; Laponche and Tillerson, 2001). Data from 2001 to 2016 for all the indicators were accessed by the World Bank database (The World Bank Data, 2018), OECD accounts data files (World Bank Data Base, 2018), International Energy Agency (IEA, 2017), U.S. Energy Information Administration (U.S. Energy Information Administration, 2017), United Nations human development index report 2017, European Union data set, and BP Statistical Review (B.P. Statistical Review, 2017).

Methodology

The use of mathematical composite indicators is the next important step once the metrics framework has indeed been built. Composite indicators are defined as economy, social, and the environment from a technical standpoint. Composite indicators may be used to evaluate nations' energy performance and carbon emissions at the national level, presenting useful data to policymakers in global negotiations. MCDA and DEA are two of the most common methods for weighing and consolidating of a well-knownnetwork of comprehensive indicators, according to previous research (Zhou and Ang, 2008). The most popular and well-known MCDA aggregation technique is widely used technique (Kang, 2002; Esty et al., 2005; Ebert and Welsch, 2004; Ebert and Welsch, 2004; Zhou et al., 2006; Ebert and Welsch, 2004; Ebert and Welsch, 2004; Ebert and Welsch, 2004; Ebert and Welsch, 2004; Ebert and Welsch, 2004; Diaz-Balteiro and Romero, 2004). We utilized the DEA-like WP technique to aggregate those indicators based on the conclusions of Zhou and Ang (2009), Zhou et al. (2010). The MCDA technique has been heavily criticized due to the subjectivity with which weights are assigned to indicators. Zhou and Ang (Zhou et al., 2006) addressed this issue by extending a DEA-like model that holds the properties of balanced combination as follows:

$$\begin{aligned} &gS_j = \max \prod_{k=1}^{n} x_{jk}^{gw_k} \\ &s.t. \prod_{k=1}^{n} x_{jk}^{gw_k} \le e, \quad j = 1, 2, ..., m \\ &gw_k \ge 0, \quad k = 1, 2, ..., n, \end{aligned} \tag{9}$$

where x_{jk} indicate the value of country j with respect to indicator k, gS_j denote the best performance of aggregated score for country j, and gw_k indicate the best set of weights. Afterward, another DEA-like model is presented as follows:

$$\begin{aligned} &bS_j = \min \prod_{k=1}^{n} x_{jk}^{bw_k} \\ &s.t. \prod_{k=1}^{n} x_{jk}^{bw_k} \ge e, \quad j = 1, 2, ..., m \\ &bw_k \ge 0, \quad k = 1, 2, ..., n. \end{aligned} \tag{10}$$

Contrary to **Eq. 9**, **10** allocates the worst set of weights to underlying indicators or sub-indicators. bS_j indicate the poor score of region j, and bw_k show the worst set of weights allocated to underlying indicators or sub-indicators. **Eq. 9**, **10** are two non-linear equations and require a bit of effort in computations due to the difficulty of non-linearity to solve them. Therefore, we get their corresponding and equivalent linear equations by taking their natural logarithm. The non-linear equations can be transformed as follows:

$$\begin{aligned} &gS'_j = \max \sum_{k=1}^{n} gw_k\, x'_{jk} \\ &s.t. \sum_{k=1}^{n} gw_k x'_{jk} \le 1, \quad j = 1, 2, ..., m \\ &gw_k \ge 0, \quad k = 1, 2, ..., n \end{aligned} \tag{11}$$

$$\begin{aligned} &bS'_j = \min \Sigma_{k=1}^{n} bw_k x'_{jk} \\ &s.t. \Sigma_{k=1}^{n} bw_k x'_{jk} \ge 1, \quad j = 1, 2, ..., m \\ &bw_k \ge 0, \quad k = 1, 2, ..., n, \end{aligned} \tag{12}$$

where $x'_{jk} = \ln(x'_{jk})$, $gS'_j = \ln(gS_j)$, and $bS'_j = \ln(bS_j)$.

Since these two indexes are presented based on best and worst sets of weights, it is reasonable and mathematically symmetric in nature to aggregate them to develop an overall composite index to aggregate the underlying indicators for performance assessment. **Eq. 13** combines gS'_j and bS'_j to construct an EPII as follows:

$$EPI_j(\lambda) = \lambda . \frac{gS'_j - gS'_{\min}}{gS'_{\max} - gS'_{\min}} + (1 - \lambda) . \frac{bS'_j - bS'_{\min}}{bS'_{\max} - bS'_{\min}}, \tag{13}$$

where $gS'_j = \ln(gS_j)$, $bS'_j = \ln(bS_j)$, $gS'_{\max} = \max\{gS'_j,\ j = 1, 2, \ldots, m\}$, $gS'_{\min} = \min\{gS'_j,\ j = 1, 2, \ldots, m\}$, $bS'_{\max} = \max\{bS'_j,\ j = 1, 2, \ldots, m\}$, $bS'_{\min} = \min\{bS'_j,\ j = 1, 2, \ldots, m\}$, and $0 \le \lambda \le 1$ is a variable for modifying and controlling. Model (13) is a minimum–maximum linear scaling pattern with a variable of λ within the range [0,1]. If decision-makers do not have a specific preference, all fundamental indications λ = 0.5. If gS_i is equal to 1, the CI_i bS_i becomes a normalized explanation of gS_i, and if bS_i is equal to 0, it becomes a normalized description of bS_i. Model (13) generates more surrounding CS, which can easily manage building indices, as a result of its virtue. The admirable features of CS_i are met. In models (16) and (17), CI_i is unit invariant, (ii) $0 < CI \le 1$ and (ii) CI_i is symmetric with regard to the right-hand side of the requirements (17). The feature of point 1 translates into the model limitations (11) and (12); if one is replaced with some other quantity, the CS remains unchanged.

Now there is the issue of disregarding all indications (zero weight) or categorizing them as overweight or underweight. Weights have the characteristic of being flexible in how they are assigned, and there are no limitations on how weights are assigned to underlying indications. In these cases, it is likely that any sub-indicators will be disregarded throughout the aggregate process. The weight limitation is a typical technique in building the composite index to guarantee each indicator's participation in the aggregation purpose. As a result, the weights of each sub-indicator are restricted as follows:

$$L_k \le \frac{w_k x'_{jk}}{\sum_{k=1}^{n} w_k x'_{jk}} \le U_k, \quad k = 1, 2, ..., n, \tag{14}$$

TABLE 1 | Average score of individual indicators.

Country	EC(koe capita)	HDI	PES (million ton)	Renewable %
The United Kingdom	3125.98	0.897	16.876	07.98
The United States	3348.98	0.887	6.8975	07.986
Japan	2876.28	0.876	3.8780	05.9876
Germany	6487.50	0.910	33.9867	13.2438
France	3897.90	0.812	6.2133	12.70
Italy	3123.45	0.865	13.0990	15.09
Canada	7934.78	0.908	261.876	20.09

where L_k and U_k show the underlying sub-indicator, respectively, in order to generate EPI and fulfill the property of $0 \leq \lambda \leq 1$. The values of L_k and U_k can be obtained by expert's specific choice. Cherchye et al. (2007) pointed out that the obtaining weights through experts' choice is easier and more practical. We allocate $L_k = 0.05$ and $U_k = 0.20$, and the environmental efficiency index is found to be in the range of 5–20%.

RESULTS AND DISCUSSION

Individual Indicator Score

The energy consumption (kilo oil equivalent) figures vary from 8120.45 (koe) to 2889.54 (koe), according to the findings. Canada has the greatest energy consumption at 7934.67 (koe), followed by Germany at 6487.50 (koe), and Japan has the least energy consumption at 2876.28 (koe) between the G7 nations.

From an economic point of view, there is a strong correlation between energy consumption and financial development. At the same time, the environmental group discourages higher energy consumption due to inverse relationships. **Table 1** shows that Japan considerably contains the lowest energy consumption while higher HDI. Higher energy usage is in line with energy equality, availability, and cost. The human development index score shows that Germany has the highest HDI score, 0.910, followed by the United States 0.883, and Canada has 0.910, while Italy has the lowest HDI score of 0.873.

Primary energy supply values range from 267.19 to 4.64. Canada shows the highest value of 482.79 of primary energy supply, followed by Germany 34.87, while Japan shows a minimum value of 4.64. Renewable energy supply values range from 22.03 to 6.31%. Canada has the highest value, 22.03%, followed by Italy at 16.52% and Germany at 14.21%, while Japan has minimum values of 6.31%. Conversely, in G7 countries, the improvement of energy sources in Germany and France to consumption in power-intensive manufacturing got off to a comparatively delayed start. This makes Germany and France to exceptionally increase energy intensity levels compared to other G7 countries. As for the environmental index, Canada and Germany top with 0.64. At the same time, Japan shows a minimum of 0.34, even though Japan has the lowest CO_2 emissions, while the environmental index incorporates carbon emission and carbon intensity environmental. The findings are consistent with Wasif Rasheed and Anser (2017), Xu et al. (2020), Ahmad et al. (2020).

The energy intensity levels vary from 0.69 to 0.39, according to the results. **Table 2** indicates that Canada has the greatest energy intensity of 0.69, while the United Kingdom and the United States have the lowest energy intensity of 0.39. Regarding energy intensity values, Canada has the best score and is considered the best performer, while the United Kingdom and the United States lie in the lowest performing countries. GHG emission per unit of energy use varies between 1356.22 and 73.670. Canada has the greatest GHG emissions per unit of energy consumption, at 1356.22, followed by Italy at 297.51, and France has the lowest, at 73.67 (World Bank, 2015).

Financial development rates vary from 2.56 to 0.73 percent. The United States has the greatest economic development of 2.56, while Italy has the lowest at 0.73. Currently, an environmental crisis necessitated the implementation of major regulations to guarantee long-term sustainability in order to preserve the environment from climate change and other degrading issues. The level of energy intensity in transition nations has been higher than the level of economic output over the last 20 years. There are considerable differences in a shift of economic activities and the enhancements in greenhouse emissions. Between 2000 and 2016, the average energy intensity of G7 economies decreased, owing to increased energy efficiency and a move toward renewable energy in economic and industrial operations, as well as a focus on carbon reduction measures (Alemzero et al., 2020b; H. Sun et al., 2020; Alemzero et al., 2020a).

Overall Composite Index Score

In **Table 3**, the total EPI value for each nation is calculated, as well as the rationale for displaying all states' EPI score. In 2001, Canada had the maximum Environmental Performance Index score of 0.72, and in 2016, it had the minimum rating of 0.64. In comparison to other G7 nations, self-reliance, financial growth, and environmental performance are more important. Fewer incorrect outputs while producing greater financial outputs, such as self-energy sources, greater financial output, and lesser environmental emissions, are all indicators of environmental success. **Table 3** indicates that France and Italy are ranked second and third, despite having Environmental Performance Index scores of 0.72 and 0.62 in 2008 and 2001, respectively, while not having to have sound and adequate energy supplies and sustainable environmental EPI values. The maximum value for France was 0.72 in 2008, up from 0.61 in 2003, while the best value for Italy was 0.62 in 2001, down from 0.53 in 2016. With an Environmental Performance Index value of 0.50, Japan ranks in second. The United Kingdom, the United States, and Germany

TABLE 2 | Average score of individual indicators.

Country	Energy intensity	GHG (kg/capita, 000)	GHG per unit of EC G.D.P. Growth
The United Kingdom	0.39	9.09	222.89	1.09
The United States	0.39	8.576	88.450	3.09
Japan	0.52	11.40	321.70	1.09
France	0.45	13.02	68.567	2.04
Italy	0.52	14.09	289.71	0.56
Canada	0.69	22.09	1289.98	3.08

TABLE 3 | Overall composite index score.

Country	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
The United Kingdom	0.50	0.42	0.50	0.44	0.44	0.42	0.39	0.46	0.42	0.42	0.43	0.39	0.38	0.42	0.42	0.38
The United States	0.48	0.46	0.43	0.39	0.41	0.42	0.39	0.39	0.37	0.38	0.35	0.38	0.35	0.39	0.41	0.34
Japan	0.61	0.57	0.56	0.55	0.52	0.49	0.49	0.47	0.44	0.44	0.47	0.49	0.47	0.44	0.45	0.48
Germany	0.68	0.67	0.61	0.66	0.63	0.68	0.69	0.72	0.71	0.69	0.68	0.69	0.71	0.69	0.66	0.62
France	0.54	0.52	0.52	0.46	0.47	0.46	0.44	0.51	0.47	0.47	0.48	0.47	0.46	0.51	0.51	0.39
Italy	0.62	0.61	0.55	0.57	0.54	0.59	0.6	0.6	0.59	0.57	0.56	0.57	0.59	0.57	0.54	0.53
Canada	0.72	0.71	0.65	0.67	0.65	0.70	0.71	0.71	0.70	0.68	0.67	0.68	0.70	0.68	0.65	0.64

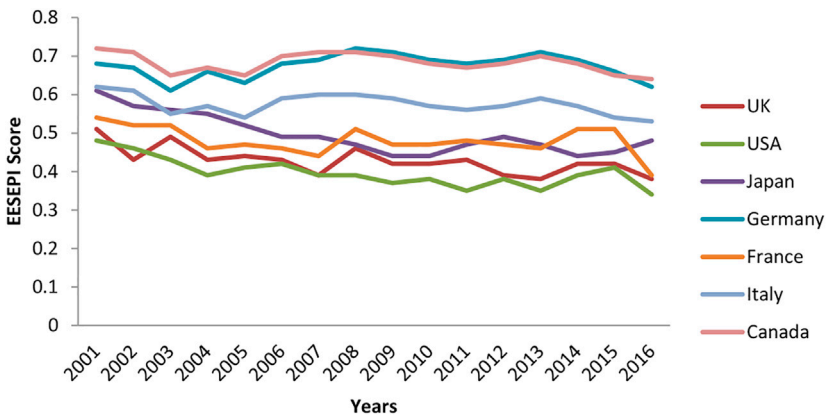

FIGURE 1 | Overall EPI score.

had Environmental Performance Index ratings of 0.43, 0.40, and 0.67, respectively.

However, comparing and ranking countries based on their average EPI scores, we opted to scrutinize each country's EPI and individual indicators score from 2001 to 2016.The EESEP scores in the region during the periods of 2001–2016 are shown in **Figure 1** shows Canada and Germany comparatively showed a smooth EPI score between 0.69 in 2001 and 0.74 in 2016. Japan's score dropped gradually from 0.65 in 2001 to 0.44 in 2010. A related direction we observed in the case of the United States is as follows: increasing energy consumption could justify the decreasing score from 2001 to 2010 in the EPI. Italy's EPI score has considerably reduced from 0.62 in 2001 to 0.53 in 2016, which may create an alarming situation even though Italy lies in a better situation similar to Germany and Canada than other countries like the United States and the United Kingdom. However, it still requires significant efforts to cope with climate change concerns, including strengthening economic development.

Overall, the United Kingdom and the United States show a decreasing score, which indicates poor performance during the periods, while Germany and Canada situation is worse than other countries, which has the worst EPI values in the country. France, also being top in the ranking, reveals a better efficiency, which implies that the country is on the right track to maintain the emissions to produce economic output, while the country had the lowest CO2 emissions among the G7 counties, ensuring the efficient consumption of their resources to generate economic growth. Italy also lies at the favorable ranking point, signifying its positive trend in increasing economic production, consuming fewer resources without

TABLE 4 | Sensitivity analysis of composite index score.

Country	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
The United Kingdom	0.47	0.40	0.41	0.41	0.40	0.50	0.49	0.40	0.40	0.45	0.40	0.49	0.42	0.49	0.50	0.49
The United States	0.45	0.41	0.41	0.42	0.42	0.42	0.54	0.42	0.41	0.46	0.43	0.42	0.43	0.51	0.51	0.41
Japan	0.57	0.51	0.52	0.53	0.51	0.49	0.56	0.46	0.47	0.42	0.42	0.53	0.50	0.50	0.50	0.50
Germany	0.69	0.63	0.62	0.62	0.60	0.65	0.70	0.70	0.75	0.69	0.68	0.70	0.72	0.69	0.72	0.59
France	0.55	0.52	0.59	0.42	0.48	0.49	0.59	0.52	0.49	0.49	0.50	0.47	0.50	0.49	0.59	0.61
Italy	0.61	0.61	0.52	0.51	0.55	0.51	0.50	0.60	0.56	0.57	0.57	0.52	0.61	0.49	0.62	0.60
Canada	0.71	0.71	0.61	0.61	0.69	0.71	0.70	0.72	0.71	0.69	0.69	0.78	0.69	0.69	0.71	0.70

increasing pollutant emissions. The United Kingdom has an averages score of 0.45, which shows that country is not performing well even though it has good environmental protection policies, that is, increasing concerns about renewable energy. Japan shows a smooth and then increasing trend of emissions, while Japan's economic situation lies among the world's largest economies. Among the G7 countries, Japan comparatively holds a good position for energy consumption, GDP, and CO_2 emission behind Germany, France, and Canada, while outperforming as compared to the United Kingdom and the United States.

Germany has the wealthiest economy in Europe. The world's leading power the United States performs well in terms of economic output, despite its significant and rapid economic improvements. The CO_2 emission levels lag behind it, among the other countries in G7 countries.

Canada, top in the ranking, includes self-sufficient energy resources, a larger share of renewable energy consumption, a stable economy, and a sufficient investment in research and development investments. Our research is aligned with a report about climate change subsidies published by Thomson Reuter Foundation in 2018, and the recent research scrutinized at G7 countries by using transparency, pledges, and commitments. The results reveal their progress toward ending the consumption, shore up, and generation of fossil fuels. Overall, France has ranked the top having a score of 63, followed by Germany at 62, the United Kingdom 47, and the United States the lowest scores with 42, and it is due to its subsidy for fossil fuel generation and its extraction from the global pact to fight against climate change in 2015.

Sensitivity Analysis

Equal weights have been given to different aspects of metrics to evaluate the response of evaluating sensitivity analysis to grade the energy, financial, and EPI of G7 nations. To create a composite ranking for the G7 area, a different weight system includes higher, medium, and low weights of several underlying variables. In contrast, an equal weight-based score shows the impact of outcomes by using equal weights.

One primary concern is to measure the changing practice energy, financial, and EPI of G7 nations by using equal weights to analyze underlying indicators. For the G7 countries, the uncertainty factors can be minimized to ensure the robust outcomes, as given in **Table 4**.

With instance of carbon dioxide data, the sensitivity analysis for data perturbation may potentially be verified due to the ambiguity inadequacy of the new consequences generated via equal weights. We do a sensitivity analysis of the G7 nations' energy, financial, and environmental presentations (see **Figure 2**). The original simulations are generated by data through the maximal multiplier, minimal multiplier, and the combination of both models into a logical combined model to eliminate the ignoring of any variable. For instance, if environmental pollution is a primary concern, the reduction of CO_2 emission remained a top priority than the reduction of energy consumption. Simultaneously, if we have an economic development as a significant development, the economic indicators remain the top priority of disproportional indicators.

TABLE 5 | Mean and standard deviation of sensitivity score.

Country	Std. dev	Mean
The United Kingdom	0.03	0.45
The United States	0.03	0.44
Japan	0.04	0.50
Germany	0.03	0.68
France	0.04	0.52
Italy	0.03	0.58
Canada	0.03	0.71

Data sampling generated in the course of equal weights and the assessment of outcomes obtained through the new data set, even though it is not an objective of our study, can yield a robustness check. The performance index compares the scores of the G7 nations' energy, financial, and environmental performance.

Table 5 shows that significantly little changes in the energy economic and Environmental Performance Index and insignificant changes in the standard deviation of the mean (almost similar to actual mean) yielded insensitivity; this may be a sign of how reliable our findings are.

Discussion

During the last 4 decades, the world's economy has grown three times in size, and because of this reason, the sustainable development issue has turned into a critical discussion. The development policy of a country needs to emphasize achieving economic efficiency while improving energy efficiency and conservation. In 2018, energy utilization exceeded 157063.77 TWh worldwide. As per projections, the planet may see a 50% increase in the level of energy demand by the end of 2050, although much of it will occur in developing Asia (IEA and

BERC 2015). The energy supply distribution will be annually 0.6 percent higher in fossil fuel (0.4 percent increase in coal and an annual 1.1 percent increase in natural gas consumption). Although a sizeable proportion (3.1 percent annually) of renewable energy would also be added as renewables, production has increased from 1.06 TW to 2.18 48 TW over 9 years (2008–2017) globally (IRENA (2018). United Nations' Sustainable Development Goal #7 requires "All people must have access to cheap, dependable, safe, and contemporary energy" (World Bank 2013). Improving the energy supply chain management and incorporating renewable energy sources in this system will help achieve high energy efficiency. The application of intricate governance and technological frameworks is another way to find sustainable energy sources. However, these may not support this notion in the long run. The electricity industry, on the other hand, is expected to bring up a slew of security issues, including budgetary, tactical, technical, and environmental (Mohsin et al., 2020b; Mohsin et al., 2018; Mohsin et al., 2019; Mohsin et al., 2021).

Electric power is the most comfortable form to curtail and detoxify compared to certain other forms of energy. It portrays the most significant improvement in generating and using energy, which is also the best way to save energy worldwide. Using energy sources would most likely rely on new regulations, given strict thresholds attached to carbon dioxide emissions emitted into the atmosphere. It would raise attention to critical sources of energy with the advanced technological system. It provides some essential qualities to turn the binding energy from non-renewable carbon fuels to integrated renewables. Scale-up and investment would be required to develop new technology to meet the increased energy demand. Despite these challenges, clean energy needs funding to transfer the standardized change initiative across the steep climb to make it viable for the public. Mohsin et al. (2019), Mohsin et al. (2020a), and Mohsin et al. (2020b) have made substantial investments in creating new technological innovations to decrease their total reliance on carbon energy (Mohsin et al., 2021).

Sources of energy supply themselves have an enormous impact on energy efficiency enhancement and intensity reduction. For example, let us examine the source of the energy supply of Luxembourger. She is rushing toward renewable energy (see **Figure 3**); this is encouraging for the reduction of energy import bills, decreasing the cost of production, and improving environmental conditions. Developing Asia required this kind of energy transaction toward renewable energy as this will not help energy efficiency and intensity. However, it will improve environmental conditions and reducing the current account deficit due to low energy import bills. It will also stabilize the exchange rate due to fewer fluctuations in the demand and supply of currency, lessening the inflation rate, and, ultimately, a positive move toward sustainable development (Yang et al., 2021; He et al., 2020; Mohsin et al., 2020b). Thus, these findings are crucial for countries taking reform initiatives to maintain sustainable economic progress with better environmental conditions. Here, energy sector reforms have a dual impact on sustainable development (positive impact) and environmental degradation (negative impact) (Tiep et al., 2021). The point is important here that power sector reforms with effective management and reforms in energy production (from non-renewable towards renewable) are key to success. This study attempted to measure some European countries' energy efficiency to picture the developing economy for their reforming policies and energy efficiency. This study has certain limitations. For example, this study investigates enough countries for a small time interval of 5-year window due to data limitation. The data set can increase to determine the big picture of this concept. The role of reform management has been decided through earlier literature on underlined countries and fluctuations in energy efficiency scores due to data limitation of such variables (Sun et al., 2019). As a result, independent research may be used to assess the degree of link among changes and their successful implementation.

The fact that increasing pollution through excessive energy consumption is caused by secondary industries explains this process (Shuai and Fan, 2020), which goes against building an improved environment (Shahbaz et al., 2018). Green: When it comes to the proportion of green zones, with statistically positive and significant coefficient values of 0.066, 0.068, and 0.056, all the estimation techniques apart from column 2 present the percentage of green zones in urban areas as being utilized for categorizing environmental guidelines. Shahbaz et al. (2018a) support the fostering of green economic growth by establishing environmental rules. The scale effect of output reflected through GDPLA at a level of 5% or above; the coefficient is scientifically positive and highly significant according to the econometric estimation, from the GDPPL perspective. Jin et al. (2018) further elaborate on land being the carrier of all living activities and human production. No financial activity can happen without land. National wealth is more likely to increase with land investment while affecting financial growth to a small extent, whereas regardless of continuous investment in technology, it is negatively impacted by land investment. In light of the results, the trade variable is insignificant in all cases. Consistency can be seen in the results of our PMG estimate and the effects mentioned before on energy emissions, which explains the theory of more substantial per capita incomes and financial efficiency created with increasing carbon emissions.

CONCLUSION AND POLICY IMPLICATION

This research created a complete and appropriate collection of indicator frameworks, which included energy financial, societal, and environmental variables linked to the energy poverty performance index (EPI). To reduce data loss during the aggregation process, the researchers developed a mathematical composite indicator. From 2001 to 2016, the G7 nations' performance was measured using the energy-economic, social, and environmental linked with energy poverty performance index (EPI). We evaluated every nation's performance based on various metrics that offer extra information in terms of relevant indicators rating prior to generating total (EPI) ratings. Many measures such as the proportion of energy self-sufficiency, energy dependence, and energy consumption per

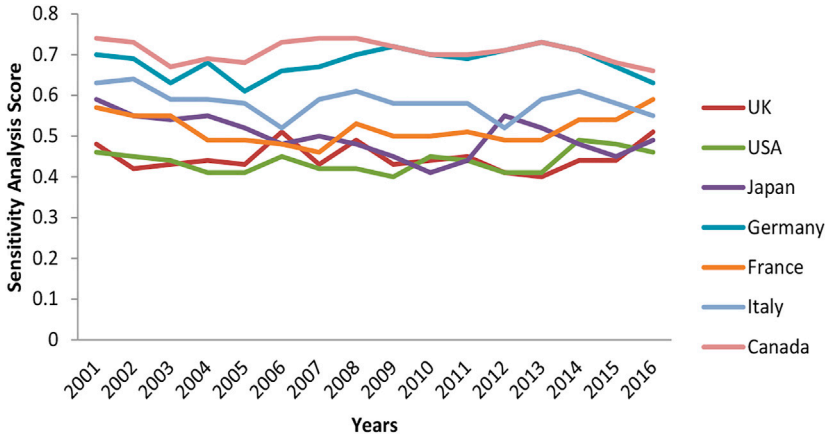

FIGURE 2 | Sensitivity analysis overall EPI score.

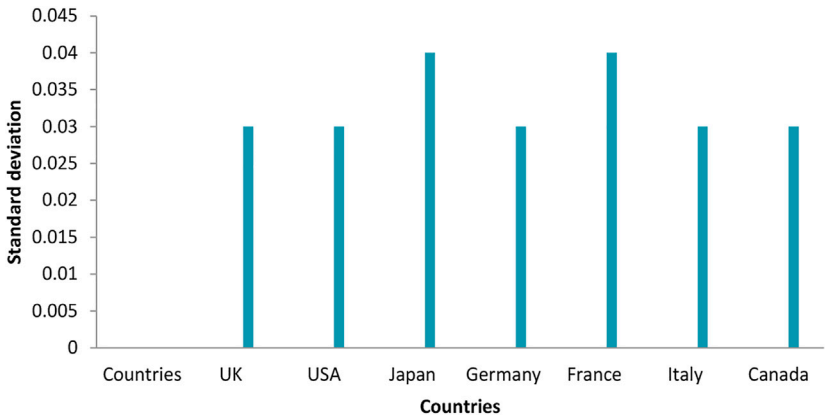

FIGURE 3 | Sensitivity analysis standard deviation score.

person indicate that Canada surpasses other nations. At the same moment, the United States is seen as a sensitive nation in terms of financial, political, and environmental performance in the G7. The findings suggest that Canada has the maximum EPI score, indicating that it has more capacity than the other G7 nations in terms of energy self-sufficiency, economic growth, and sustainability practices. France and Italy are ranked second and third, respectively. Japan is next with 0.50 EPI ratings, whereas the United States has the lowest average EPI, despite having the most economic development among the G7 nations. The following is the strategy that we have proposed.

There should be a strong legislative framework and initiatives in place to enhance the amount of clean, cheap energy available while maintaining a financial growth and development. At the corporate level, regulations should be adopted and environmental priorities should be prioritized, such as sidewalk consciousness. The current regime should concentrate its efforts on reducing pollution by endorsing and implementing energy efficiency policies. The administration should manage massive energy requirements while balancing financial and environmental considerations (L. Sun et al., 2020b; H. Sun et al., 2020; L. Sun et al., 2020a). With an increase in GDP growth that results in high GHG emissions (i.e., in Canada's case, due to growth in its GDP), it is easy to see a substantial relationship between GDP growth and GHG emissions. Challenges related to energy security and more significant GHG emissions per capita are faced by other nations that utilize more energy. Emissions and energy security per capita is a significant challenge in nations, including the developed and underdeveloped countries, focusing on utilizing high energy as fossil fuel subsidies cause high GHG emissions (Petrović-Ranđelović et al., 2020). GHG emissions are most likely to be reduced emissions by the year 2030 down to 12% due to the reduction in subsidy forecasted for Australia. The significant role of fossil fuel is evident through the GHG values depicting the energy type in these nations. On the contrary, the RE utilization is high for the countries with low GHG emissions (Yoshino et al., 2020).

Energy policymakers and environmental policy analysts should globally advocate the contemporary and growing

concern of sustainable development and global warming, and there should be increasing environmental performance through benefits. Energy conservation practice should be implemented to decrease carbon-based energy consumption, while increasing demand and consumer behavior toward energy consumption should be monitored at the government level. We recommend the future study as an extension of the current study by combining the mathematical composite indicators and the Malmquist distance radial function to construct the energy poverty performance indicator with financial, societal, and environmental implications (EPI).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JH: Investigation, Data curation, Writing-original draft. HL: Formal analysis, Validation, Writing-original draft. SI: Resources, Writing–original draft. XW: Writing–review and editing.

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Nexus Between Green Finance, Energy Efficiency, and Carbon Emission: Covid-19 Implications From BRICS Countries

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The threats of climatic change on life, health, and the environment have been regarded by the joint consensus of scholars in the recent decades. With the advancement of global green development, green finance has paved the way for the government to respond to the challenges of climate change by providing mature financial services, appropriate financing, investment, and project funds related to environmental protection. In this context, green finance was proposed, and the relationship between green finance, renewable energy, and carbon emissions in the BRICS countries from 2000 to 2018 was further studied based on the quantile regression model. The presence of cross-sectional dependence in panel results is tested through CD and LM methods. The findings show the negative effect of green finance and non-fossil energy consumption on CO_2 emissions. Furthermore, economic growth, trade openness, energy consumption, and foreign direct investment increase the CO_2 emissions. Finally, the research results confirm that green finance is the best financial strategy to reduce carbon dioxide emissions.

Keywords: green finance, quantile regression, CO_2 emission, energy efficiency, non-fossil energy consumption

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1 INTRODUCTION

The increase in energy consumption due to fossil fuel leads to increased greenhouse gas (GHG) emissions as recorded in recent years and in turn affects economic growth. Fossil fuels, such as coal and petroleum, are the main ingredients of industrial revolution, whereas industrial growth plays an important role in economic growth and uses fossil fuels as a powerful catalyst (Zhang et al., 2021). Moreover, the threats of climatic change on life, health, and the environment have been regarded by the joint consensus of scholars in the recent decades. Similarly, carbon emission is regarded as the main reason for climate change and, therefore, is stressed by many researchers and policymakers to overcome a global environmental disaster. Therefore, "the amount of GHG could double by 2035 from the pre-industrial level if no counter measures are taken," according to Stern et al. Hence, the average worldwide temperature will turn higher than 2°C in case of no action taken for GHG emission reduction, which is validated by the 2016 conference of the Paris Agreement (Zhang et al., 2021; Hsu et al., 2021; Ehsanullah et al., 2021). Furthermore, all aspects of life are threatened by the increasing temperature, which increases levels of GHG emissions and impacts nature and human life, according to the environmental institutions and environmental experts (Anser et al., 2020). Similarly, a rapid increase in sea levels, droughts, intense wildfires, increased hurricanes, less crops and fresh water, and a higher ice melting rate are expected if the threshold of 2°C is

crossed, as stated by the Medical Society Consortium on the Climate and Health report (MSCCH). This decreases the quality of water, air, food, and health (Ullah et al., 2021; Abokyi et al., 2019).

Increase in CO_2, methane gas, and nitrous oxide is the main source of climate change. Most studies, including the Kyoto Protocol and the UN Convention on Climate Change (UNFCCC), fail to provide sufficient information on climate change difficulties (Li et al., 2021; Chien et al., 2021) and (Iqbal et al., 2021). Many researchers and scholars claim that environmental quality is potentially improved by implementing new regulations and economic policies; however, improving environmental quality through energy conservation reduces economic development (Alemzero et al., 2020a; Alemzero et al., 2020b). In addition, creating a balance between environmental degradation reduction and maintaining economic growth remains a major challenge for policymakers, which challenges them to reduce greenhouse gas (GHG) emissions and ensure availability of consistent and inexpensive energy sources (Iqbal et al., 2021) and (Zhang et al., 2021). Thus, green finance paves the way for governments aiming to face the climate change challenge by providing sophisticated financial services, appropriate financing, investments, and funds for projects related to environmental protection. Therefore, green finance represents an obvious way forward for the countries fighting against climate change. In essence, green finance aims to provide investment, financing, operating funds, and other financial services for environmentally friendly projects, with environmental protection as the main driver. Moreover, the leadership of a country needs to commit to factors, such as project selection and project financing (Koomson and Danquah, 2021), which indicate how injecting green finance into the industrial sector is more favorable than the renewable energy sector due to the reduction in industrial pollution and energy consumption, caused by this technological advancement in the industrial sector (Yu, 2021). Therefore, the behavior of financial institutions to support financing of energy conservation and environmental protection projects is referred to as green finance (Dong et al., 2021). Similarly, rational capital allocation and real economy representation is the essence of finance, whereas the behavior of financial institutions to actively support the financing of energy conservation and environmental protection projects is referred to as green finance (Guild, 2020; Baloch et al., 2020; Chandio et al., 2021).

This process enables industrial structure adjustment and economic development promotion. Moreover, green finance supports the transfer of capital from pollution and energy-intensive industries to industries with advanced concepts and technologies. In addition to promoting environmental sustainability and governance, green finance is considered as an efficient solution for environmental deterioration, as stated by Chen et al. (2021), which connects finance and ecology. Moreover, technological and innovation investment is supported by green finance (Nawaz et al., 2021), which highlights green finance as the most suitable way to fight against environmental pollution for both developed and developing countries. Investing and financing environmentally friendly projects are the main aspects supported by green finance (Khan et al., 2018; Khezri et al., 2021; Liu et al., 2021; Lv and Li, 2021; Okere et al., 2021).

Environmental issues are never incorporated into finance by any research. This study, therefore, has three major contributions:

1) This study is the first to explore the relationship between green finance, renewable energy, and carbon emissions in the BRICS countries. Different from previous studies, this study focuses on green finance instead of considering the impact of financial development on environmental variables.
2) The research constructed a green finance index, which is composed of three financial indicators: green credit, green securities, and green investment.
3) This study draws a comparison between OLS regression and quantile regression. The advantages of quantile regression are as follows: 1) it proves the entire conditional distribution of the explained variable, not the mean value of the explained variable under this condition. Therefore, based on different explanatory variables, CO_2 emissions are affected differently, explaining how the regression coefficients of different quantiles are usually different, and outliers indicate the significant impact of important information. 2) The estimated coefficients of quantile regression are much more robust than those of OLS regression, and the random error term through quantile regression does not strictly meet the classic econometric assumptions such as zero mean, homoscedasticity, and normal distribution. However, for abnormally distributed variables, the estimated values of parameters in quantile regression are more robust.
4) The implementation of green investment industrial policies at the country level poses a challenge to the leadership of the BRICS countries, considering the critical nature of policy implementation.

The rest of the article is organized as follows: **Section 2** discusses the literature related to green finance, renewable energy, and CO_2 emissions. **Section 3** presents research design, in which we explain the green finance calculation method, data source, and model specification. Moreover, **Section 4** discusses empirical results, and finally, **Section 5** provides the conclusion and policy recommendation for the decision maker.

2 LITERATURE REVIEW

Green development is an old concept in history that has evolved in conformance with the trend from being a mere ethical and aesthetical initiative concerned with ecological wellbeing to a comprehensive support system with economic, legal, and political dimensions. It is a manifestation of the currently improved realization of human–nature and human–social relationships. In its essence, finance facilitates resource allocation to serve real economic development, whereas green finance provides the support for environmental protection and energy conservation projects. Green finance is vital for improving the

structure of industry toward sustainable economic development. Its role is not limited to financing environmental governance but also includes resource reallocation from intensive fossil-energy industries to advanced technology sectors (Westerlund and Edgerton, 2008; Xu et al., 2021; Zaidi et al., 2019; Zhou et al., 2020).

The research field of environmental policy and green finance has grabbed a lot of attention recently. Some researchers have focused on developing a definition and establishing a framework for green finance (Agyekum et al., 2021) and (D. Zhang et al., 2021). Tolliver et al. (2019) explained the present situation of green finance and stressed the similarity between the two concepts of green finance and climate finance. On the other hand, limited research addressed the relation between finance and ecology. (Guild, 2020) pointed out the necessity of financing solar energy for promoting environmental sustainability. Similarly, (Jinzhou, 2011) suggested environmental finance to mitigate environmental deterioration based on the premise that green finance increases technology investments, especially non-fossil energy technologies, and promotes innovation (Sandberg et al., 2019). Nonetheless, the relationship between green finance and CO_2 emission is still under investigation. Saeed Meo and Karim (2021) analyzed the impact of green finance on CO_2 emissions in the top ten supporters of green finance economies (Canada, Hong Kong, Denmark, Japan, Norway, New Zealand, Sweden, the United Kingdom, Switzerland, and the BRICSates). They found that green finance negatively influences carbon emissions; nonetheless, the impact varies throughout different quantiles. The variance in the impact is attributed to the market conditions of green finance and different countries. Overall, the study advocates green finance as an effective financial tool for carbon emission mitigation (Ozturk and Acaravci, 2013; Saidi and Mbarek, 2017).

The study of Guild (2020) has also analyzed the associations between green finance, non-fossil energy, and CO_2 emission in China and consequently discovered a significant relation between green finance and carbon intensity. Hao et al. (2021) went a step further to study green bond financing and its impact on environmental protection; however, their study did not recommend any policies for sustainable development. On the contrary, the study of Huang and Lei (2021) performed a comprehensive review on the literature related to the significance of green bonds for building a low-carbon economy. The study listed some recommendations that are significant for being developed in the pre-SDG epoch. These policies were discussed again recently in the study of Zaid et al. (2018), stressing the importance of green bonds to promote firm environmental responsibility and utilize them to achieve the sustainable development goals. Unlike Flammer, (Saraswat and Digalwar, 2021) stressed the firm social responsibility instead of environmental responsibility while assessing the role of green bonds in this regard and the delivery of the firm actions through their CSR activities. Jiang et al. (2020) conducted an empirical analysis on the relationship between green finance and environmental and social sustainability based on the S&P 500 Global Green Bond Index and the S&P 500 Environmental and Social Responsibility Index between 2010 and 2020 using quantile-on-quantile Regression and wavelet multiscale decomposition approaches and pointed out a gradual negative transformational impact of green finance on environmental and social responsibility (Sun et al., 2020b) and (Sun et al., 2020a) and furthermore, various researcher, such as (Chandio et al., 2020; Sun et al., 2020c).

TABLE 1 | Green finance index.

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.845	2.693	0.9485	0.9485
Comp2	0.152	0.1487	0.0506	0.999
Comp3	0.0029	—	0.001	1
Eigenvectors				
Variable	Comp1	Comp2	Comp3	—
GC	0.5905	−0.2018	−0.7814	—
GS	0.5636	0.7962	0.2202	—
GIN	0.5777	−0.5704	0.5838	—
Correlation matrix				
Variable	GC	GS	GN	—
GC	1	—	—	—
GS	0.922	1	—	—
GIN	0.9867	0.8579	1	—

3 RESEARCH DESIGN AND MODEL SPECIFICATION

3.1 Research Design

Financial development is important for promoting industry. CO_2 emissions and industrial structure are closely associated, according to prior studies. Similarly, renewable energy consumption is also shown to affect carbon emission reduction. This research assesses the relationships between green finance, renewable energy use, and CO2 emission using quantile regression, considering green finance and renewable energy consumption as the core independent variables, whereas CO2 emission is the independent variable. Furthermore, the results are strengthened by using control variables, such as foreign direct investment (FDI), per capita GDP (GDP), research and development (RD), trade openness (Trade), and energy consumption (EC).

3.1.1 Green Finance Index

The flow of financial investments flowing into sustainable development projects and initiatives, environmental products, and policies encouraging development of a more sustainable economy is referred to as green finance. We construct a green finance indicator with three sub indicators, 1) green credit (GC): green loans and deposits, such as mortgage loans and project loans, are collectively referred to as green credit. Green credit is measured as the company's one-year green credit divided by the total credit, that is, the ratio of green loans to listed companies. 2) Green securities (GS): the green securities index is calculated as the ratio of the value of environmentally friendly companies to the total value of all companies. 3) Green investment (Gin): investing in protecting the environment and conserving energy is

TABLE 2 | Summary statistics.

Variable	Description	Mean	Standard deviation	Minimum	Maximum
GFI	Green finance index	0.39	0.02	0.37	0.41
CO2	MLN_TONNE	3.72	0.03	3.68	3.76
R&D	MLN_USD	5.64	0.06	5.56	5.76
Trade	%GDP	1.43	0.05	1.35	1.49
EC	MLN_TOE	3.35	0.01	3.33	3.37
RE	% of total final energy consumption	0.80	0.10	0.65	0.94
FDI	% GDP	0.23	0.15	0.01	0.53
GDP	GDP per capita	4.68	0.07	4.56	4.80

Notes: Std = standard deviation and all the values are transfer into natural logarithm.

referred to as green investment. This study focuses on the public sector, and therefore, we compute green investment by dividing public spending on energy conservation and environmental protection by the total expenditure. The two reasons for selecting this index include 1) the lack of authoritative data on statistics for the investment in environmental protection and energy conservation for the private sector and 2) the impact of private investment on green finance is reflected through the green securities and green credit financing. Hence, the impact of government spending on the green finance index is explained better by removing private investment (Ikram et al., 2019a; Sun et al., 2019; Ikram et al., 2019b).

A comprehensive green finance (GF) index, constituted by green credit, green investment, and green securities is constructed by employing PCA, which captures the main information from the initial data. Moreover, the PCA results are shown in **Table 1**, where 70% of the standardized variance is accounted for by the first principal component (PC1), and is recorded at an eigenvalue of >1, utilizing it to construct the financial development index.

3.1.2 Data

The descriptive statistics of CO_2 emission and green finance are shown in **Table 2**, which also demonstrates the share of renewable energy consumption, energy consumption calculated in British units of thermal energy per person, trade openness calculated as the percentage of trade to total GDP, GDP calculated in trillions of USD in current value, and foreign direct investment in trillions of dollars, respectively. Similarly, recorded with a more than six-fold increase, clean energies show a dramatic and steady increase from 10,669.87 Mt (2000) to 67,933.13 Mt (2018), whereas the gradual decline of CO_2 emissions is recorded at 0.02995 to 0.01131 from 2000 to 2018, which is more than half of the previous value.

3.2 Model Specification

3.2.1 Cross-Sectional Dependence Test

The associations between the studied countries make cross-sectional dependence (CD) an appropriate choice for panel data. Consistent and unbiased results are achieved only by detaching it from cross-sectional dependence; hence, testing the cross-sectional dependence becomes eminent and two tests are used throughout the study. The tests were suggested by Pesaran and Breusch and Pagan, respectively. The following equation represents the test of Pesaran:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{j=i+1}^{N}\rho_{ji}\right),$$

where the sample size is represented as N and time period as T, whereas i and j represent the correlation of errors for the countries addressed. Similarly, the second cross-sectional dependence test, developed by Breusch and Pagan, is a Lagrange multiplier (LM), depicted as follows:

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it}$$

where the cross-sectional proportions are identified by i and the time period as t, and the cross-sections are independent according to the null assumption and mutually dependent on the alternative assumption.

3.2.2 Panel Unit Root Tests

The integration and regression techniques are employed only after checking the unit root. The unit root in the data is assessed by the first-generation unit root test, where cross-sectional dependence is not considered and the limited functions of the first-generation tests make them inefficient. We conduct second-generation root tests to check the cross-sectional dependence in panel data and investigate the roots of units using center augmented Dickey–Fuller (CADF) and cross-cut IPS (CIPS) for reliable results.

3.2.3 Panel Cointegration Test

Cointegration between the variables is analyzed after testing the cross-sectional dependence and unit roots, as proposed by Westerlund and Edgerton. The application of the test takes cross-sectional dependence into account, allowing heterogeneity in error correction models. The coefficients φN and t-test τN, derived from the LM unit root tests, are included in the cointegration tests as two different versions producing reliable results.

3.2.4 Panel Quantile Regression

The fixed effect panel quantile regression method is used to avoid individual heterogeneity, differing from the (PQR) model utilized. The knowledge benefits of the quantile regression give

it preference and a reliable estimator is used to provide accurate measurements and calculations, whereas the properties of means and quantiles differ drastically. Individual error terms are generated by the fixed effect PQR, considering heterogeneity on an individual and distributional level which also controls the outliers. Hence, in case of the error term not following a normal distribution, the PQR, which is better than the CM method, is used, whereas the CM method is preferred when error terms are distributed normally. Nevertheless, it is difficult to satisfy the conjecture of normality, which drives the CM method to produce biased estimates. Hence, PQR provides detailed insights regarding various carbon emission determinants at different economic development stages suitable for the objective of this study.

The issue of the renewable energy production determinants, which is a sensitive cause stressed by the recent policy and economical literature, is also examined by this research. Hence, the following regression equation is estimated to test the relationship between non-fossil energy production, political stability, governance, and financial development, including other control variables:

$$CO2_{it} = \alpha_0 + \alpha_1 GFI_{it} + \alpha_2 NFE_{it} + \sum_{j=1}^{K} \lambda_j Z'_{jit} + \tau_i + \epsilon_{it}, \quad (1)$$

where the natural logarithm of environmental quality (CO_2) is determined as CO_2, the country as i, and the time period as t, which remains constant across countries but not overtime as a parameter. Similarly, the structural logarithm of the green finance indicator and renewable energy consumption, along with the interaction term between GFI and NFEC, is represented as GFI and NFE. Moreover, the vector of relevant control variables per capita GDP (GDP), foreign direct investment (FDI), technological innovation (RD), trade openness (Trade), and energy consumption (EC) is represented as Z.

3.2.5 Estimation's Method

The impact of green finance and renewable energy on CO_2 emission in BRICS is examined in this study by developing a panel quantile regression model. The objective of the quantile regression approach initiated by Koenker and Bassett (1978) is to assess the conditional quantile functions and to generalize the idea of univariate quantile estimation, which explains the formulation of conditional distribution of the variable through quantiles as functions of the observed explanatory variables. The symmetric features of the outcome variable distribution are easily examined by this method in contrast to the ordinary least square (OLS) method due to its high responsiveness to outliers. The quantile regression accounts for outliers and analyzes the determinants of renewable energy production across the conditional distribution. Moreover, the results of the OLS regression describe the "average" renewable energy production country, appreciating the mean effect, where the mean effect caused by OLS regression does not clarify the coefficients from the heterogeneous responses' model, as demonstrated by Koenker and Bassett, 1978.

Alternatively, in case of factors of interest with varied impacts throughout the conditional distribution of the dependent factor, it is suitable to apply the quantile regression model. Several studies have recently combined quantile regression with panel data (Graham et al., 2018). Hence, panel data enable the incorporation of fixed effects to authenticate the in-group variations in the mean regression model, whereas the underlying model is altered by the additive fixed effect (Mohsin et al., 2018a).

A robust inference is provided by the newly proposed method by Powell, sufficient for quantile estimators with fixed effect (μ_i), relying on the estimation of the distribution of $Y_{it} \mid X_{it}$ (Y_{it} given X_{it}) instead of $Y_{it} - \mu_i | X_{it}$ ($Y_{it} - \mu_i$ given X_{it}). The latter estimate is not always consistent where the inability of the additive fixed effect models to generate information on factors of policy effects and on the outcome distribution due to observations at the top of $Y_{it} - \mu_i$ distribution and at the bottom of Y_{it} is the gist of what Powell proposes (Mohsin et al., 2018b; Mohsin et al., 2018b; Ikram et al., 2019a). Therefore, the Powell method (2016) furnishes point estimates that could be explained in the same way as the ones resulting from cross-sectional regression. Furthermore, this method is consistent for short panel data and the underling model of this article, considering Powell's approach is as follows:

$$Y_{it} = \sum_j X'_{it} \alpha_{j(\varepsilon^*_{it})}, \varepsilon^*_{it} \sim \varepsilon(0, 1), \quad (2)$$

where renewable energy production is represented as Y_{it} , main explanatory factors as X'_{it}, the parameter of interest as α_j , and the error terms and the proneness for the outcome is represented as ε^*_{it}, which is time-varying for some time-fixed function of various error terms. Moreover, $X'_{it}\alpha_j(\varnothing)$ is strictly rising in $\varnothing$, whereas quantile regression depends on the following conditional restriction with the $\varnothing$ th quantile of Y_{it} :

$$P(Y_{it} \le X'_{it}\alpha_j(\varnothing) | X_{it}) = \varnothing, \varnothing \epsilon [0, 1]. \quad (3)$$

Hence, the probability of the latent outcome factor is lower than the quantile function and identical to all X_it and identical to $\varnothing$, according to **Eq. 3**. When fluctuation and the instrument are orthogonal, the probability to fluctuate is allowed by the quantile regression estimator for panel data of Powell (2016), and therefore, the following equation expresses the Powell's estimator, considering the conditional and unconditional restrictions:

$$P(Y_{it} \le X'_{it}\alpha_j(\varnothing) | X_i) = P \quad Y_{is} \le X'_{is}\alpha_j(\varnothing) \quad X_I \quad , X_i$$
$$= (X_{i1}, \ldots, X_{iT} \quad (4)$$

A numerical optimization, based on adaptive Markov Chain Monte Carlo sampling (MCMC), is employed to estimate the quantile regression model, which relies on multivariate normal distribution proposed by Baker (2014) for optimization.

4.5 Granger Causality Tests

The relationships between CO_2 emissions and other variables are demonstrated by the long-term estimation techniques. However, awareness about the direction of the short-term relationships is eminent for policymaking. Conclusively, the causal relationship between the variables is determined with the causality test by (Dumitrescu and Hurlin, 2012), whereas the vector autoregressive (VAR) method is used on stationary results,

TABLE 3 | Cross-sectional dependence test results.

Variable	CD test	Scaled LM test	Pagan LM test
CO2	10.02***	62.32***	1,068.07***
GFI	30.29***	93.48***	1,550.80***
NFEC	50.57***	124.64***	2033.53***
EC	32.58***	87.38***	1,456.21***
Trade	29.91***	110.62***	1816.32***
GDP	46.88***	160.59***	2,590.47***
RD	7.11***	44.35***	789.62***
FDI	30.16***	107.09***	1761.69***

*Note: variables are ln-transformed. *** represents 1% significance level.*

TABLE 4 | Cointegration test results.

Model	No shift		Mean shift		Regime shift	
	Statistic	*p*-value	Statistic	*p*-value	Statistic	*p*-value
LM_{τ}	−3.2959	0.0107	−5.3836	0.0001	−4.7054	0.0001
LM_{ϕ}	−3.8118	0.0019	−5.3638	0.0001	−4.3355	0.0001

Note: models are run with maximum five factors.

considering data heterogeneity, to determine the short-term relationship between variables by applying the test individually on regression.

4 EMPIRICAL ANALYSIS

4.1 CD, Unit Root, and Cointegration Tests

The presence of cross-sectional dependence in panel results is tested before evaluating the stationary properties of the variables, which is done through CD and LM methods as shown in **Table 3**. Hence, the null hypothesis is rejected to observe cross-sectional dependence between variables, according to the empirical findings, followed by a check for table existence of each variable, considering cross-sectional dependency. Moreover, **Table 4** shows the results for CIPS and CADF tests, indicating the root problems at the state level, such as CO_2 emissions, green finance, non-renewable energy consumption, energy consumption, trade openness, economic development, R&D, and foreign direct investment, respectively. However, unit root (stationary) is absent in the first difference in such variables.

4.2 Panel Quantile Regression

The results of the panel quantile regression model at the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th individual quantiles are reported in **Table 5**. In our model, CO_2 is the dependent variable, whereas green finance and renewable energy consumption and other control variables are represented as independent variables. In addition, as the results show, the common observations in all variable estimates are statistically significant at a significance level of more than 5%. It can be seen from the research results that the impact of the green finance index on CO_2 emissions is obviously heterogeneous. The results show that at the lower 10th quantile and the middle 40th quantile, the effect is statistically significant and negative at the 1% level. On the other hand, the elasticity of green finance is statistically significant and positive in the 50th, 60th, 70th, 80th, and 90th quantiles. However, the negative coefficient of the green finance index is sufficient to support the hypothesis of this study that green finance has a significant negative impact on CO_2 emissions. It implies that green finance reduces CO_2 emissions in BRICS. Similarly, the dependence structure between different quantiles of green finance and CO_2 emissions was tested by Saeed Meo and Karim (2021), who reported the negative relationship between green finance and CO_2 emission and confirmed the negative impact of green finance on CO_2 emissions, showing a variation across quantiles.

In addition, in the case of non-fossil energy consumption (NFEC), the research results show that NFEC has a significant negative impact on carbon dioxide emissions at a 1% significance level at the 10th, 25th, 50th, and the higher 90th quantile. This shows how the BRICS countries regard renewable energy as an important tool for mitigating CO_2 emissions. Similarly, a decrease from 0.38 to 0.68% is recorded in CO2 emission in the BRICS with a 1% increase in non-fossil energy, constituting magnitude for the coefficients from 0.38 to 0.68. The impact of non-fossil energy is considered to be the key factor to high CO_2 emissions and has a more obvious impact at higher quantiles, prompting the authorities to use renewable energy as a key factor to achieve the greatest growth. The research results are particularly interesting because it shows that the development and expansion of financial activities promote the development of the renewable energy sector through the provision of equity financing, debt, and capital loans for green projects (Charfeddine and Kahia, 2019; Khan and Ozturk, 2021; Wang et al., 2021). The findings of the study are also consistent with the results of the study by (Danish et al., 2019) for OECD countries and the study by (Zaman et al., 2021) for China and (Ryan et al., 2020) the economy-wide impact of renewable energy expansions in Chile's energy mix and (Mehmood, 2021) for G11 economies.

Table 7 confirms the results of the control variables. At the 1% significance level, all control variables except R&D show statistically significant positive impact on CO_2 emissions. In terms of GDP, the impact of economic growth on carbon dioxide emissions is positive and statistically significant. Therefore, the results indicate that the level of CO_2 emissions increases as GDP increases. From the consistency of the results, the entire distribution of CO_2 emissions follows the same trend. However, the magnitude of the coefficients varies from 1 to 2.4%, higher quantiles show effects with less prominence and as compared to the 10th quantile, the impact on CO_2 emission is twice as less for the 20th, 50th, 70th, and 90th quantiles. This means that the increase in disposable income brought about by economic growth can be used to stimulate the deployment of non-fossil energy sources and promote the development of environmental protection technologies. Our research results are supported by Jaforullah and King (2015), who concluded that the per capita consumption of fossil energy is the determinant of US real GDP growth. Moreover, Boontome et al. (2017) highlighted that GDP has a positive and statistically significant impact on CO_2 emission in Thailand. Therefore, the levels of GDP determine the effect of economic growth on CO_2 emission in the BRICS, whereas the significance of FDI becomes stable with a decreasing trend

TABLE 5 | Panel quantile regression with fixed effects results.

Variable	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
GFI	−0.018***	−0.026***	−0.024***	−0.021***	0.025*	0.024*	0.021*	0.022**	0.024**
	(0.007)	(0.007)	(0.006	−0.004	−0.003	−0.002	−0.004	−0.002	−0.002
NFEC	−0.038**	−0.049**	−0.04	−0.071***	−0.062***	−0.060***	−0.080***	−0.086***	−0.061***
	(0.034)	(0.024)	(0.025	−0.02	−0.017	−0.013	−0.016	−0.013	−0.012
EC	2.609***	1.783**	1.219**	0.679	0.898**	0.994***	0.337***	0.315***	0.196***
	(0.857)	(0.709)	−0.571	−0.497	−0.432	−0.346	−0.432	−0.308	−0.195
Trade	0.063**	0.028**	0.022**	0.038**	0.017**	0.009***	0.005***	0.003***	0.003***
	(0.031)	(0.025)	−0.016	−0.019	−0.018	−0.018	−0.016	−0.008	−0.008
GDP	2.339***	2.213***	1.650***	1.459***	1.080***	1.048***	0.905**	0.699***	0.383**
	(0.655)	(0.52)	−0.468	−0.415	−0.363	−0.321	−0.364	−0.222	−0.148
RD	−0.393***	−0.398***	−0.417***	−0.274**	−0.271**	−0.265**	0.326*	0.343	0.339*
	(0.037)	(0.028)	(0.025)	(0.02)	(0.016)	−0.013	−0.016	−0.014	−0.011
FDI	1.531***	1.511***	1.486***	1.463***	1.443***	1.426***	1.404***	1.419***	1.379***
	(0.054)	(0.034)	−0.034	−0.026	−0.02	−0.014	−0.023	−0.021	−0.026
Constant	−11.305***	−9.071***	−6.602***	−4.987***	−4.552***	−4.627***	−2.849***	−2.323***	−1.417***
	−2.038	−1.57	−1.283	−1.125	−0.963	−0.794	−0.957	−0.648	−0.519
N	308	308	308	308	308	308	308	308	308

Note: Standard errors in parentheses, *** p < *0.01,* **p < *0.05,* *p < *0.10.*

TABLE 6 | Robust results.

Variable	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
GFI	−0.005***	−0.005***	0.002***	0.002**	0.003**	0.001**	0.004***	0.002***	0.002***
	(0.009)	(0.009)	(0.005)	(0.003)	(0.003)	(0.002)	(0.005)	(0.004)	(0.002)
NFEC	0.036	0.036	0.026	0.039**	0.011	0.006	0.003	−0.001	0.003
	(0.025)	(0.025)	(0.018)	(0.018)	(0.02)	(0.014)	(0.013)	(0.007)	(0.008)
EC	1.679**	1.679**	0.802	0.614	0.850**	0.377	0.321	0.137	0.196
	(0.839)	(0.839)	(0.605)	(0.457)	(0.416)	(0.328)	(0.37)	(0.299)	(0.195)
Trade	−0.046	−0.046	−0.056**	−0.074***	−0.058***	−0.068***	−0.088***	−0.070***	−0.061***
	(0.034)	(0.034)	(0.025)	(0.019)	(0.017)	(0.013)	(0.014)	(0.014)	(0.012)
FDI	1.515***	1.515***	1.465***	1.442***	1.433***	1.419***	1.402***	1.402***	1.379***
	(0.051)	(0.051)	(0.033)	(0.023)	(0.02)	(0.017)	(0.021)	(0.016)	(0.026)
GDP	2.580***	2.580***	1.562***	1.154***	1.259***	1.050***	0.873***	0.786***	0.383**
	(0.639)	(0.639)	(0.476)	(−0.39)	(0.353)	(0.31)	(0.275)	(0.236)	(0.148)
RD	−0.386***	−0.386***	−0.384***	−0.362***	−0.365***	−0.346***	−0.314***	−0.344***	−0.339***
	(0.028)	(0.028)	(0.025)	(0.018)	(0.016)	(0.013)	(0.015)	(0.009)	(0.011)
Constant	−9.705***	−9.705***	−5.487***	−4.151***	−4.815***	−3.305***	−2.719***	−2.146***	−1.417***
	(1.785)	(1.785)	−1.357	(1.044)	(0.911)	(0.715)	(0.771)	(0.646)	(0.519)

pattern. Similarly, FDI shows a positive value at other quantiles, except the higher quantile, showing a positive value with a weaker effect, suggesting the secondary effect of FDI with CO_2 in the BRICS getting positively affected by foreign direct investment. In case of R&D, the effect is more substantial for the low quantiles and weak for the higher quantiles. This means that lower-cost environmental protection technologies are favored by the advanced technological innovation sector. In addition, the recent literature is consistent with our findings, that is, the importance of technological innovation to the promotion of clean energy, which regards technological innovation as a prerequisite for promoting clean energy (Blondeau and Mertens, 2019; Pejović et al., 2021). Therefore, advanced technological innovation can easily promote the development of renewable projects, which is a necessary prerequisite for the development of renewable energy (Goh and Ang, 2018). Nevertheless, enhancement of economic feasibility, raising the awareness of economic agents, fostering stockholder engagement, and promoting consumer engagement in green energy investment are some of the essential features to conduct the ongoing R&D process. According to the results, trade openness and fossil energy consumption are considered as important drivers of CO_2 emission in the BRICS.

4.3 Robustness Check

The stability of the estimated results is tested through several robustness tests, applying Canay's fixed quantile regression model followed by an alternative proxy indicator for the green finance index, which examines the variation in the main findings.

4.3.1 Canay's (2011) Fixed Effect Quantile Model

A Canay's (2011) fixed-effect quantile model, extracted from the fixed effect model, is developed to assess the robustness of our empirical analysis, whereas **Table 6** shows the regression estimates. Similarly, **Table 6** shows the corresponding Canay's panel quantile regression diagrams, and therefore, the results of

TABLE 7 | Robust analysis using the original variables green credit, green investment, and green securities.

Variable	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Panel A: independent variable: green credit									
Green_Cr	−0.011***	−0.003***	0.001*	0.001**	0.002**	0.003***	0.001***	−0.001***	0.0004***
	(0.005)	0.008)	(0.004)	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
NFEC	−0.071**	−0.056**	−0.054**	−0.071***	−0.061***	−0.061***	−0.080***	−0.080***	−0.068***
	(0.032)	(0.027)	(0.025)	(0.020)	(0.018)	(0.014)	(0.014)	(0.013)	(0.013)
EC	2.829***	1.416**	1.229**	0.68	0.908*	0.963**	0.33	0.352	0.194
	0.881)	0.673)	0.552)	0.513)	0.462)	0.374)	0.402)	0.291)	0.194)
Trade	0.076**	0.032	0.026	0.038**	0.017	0.01	0.006	0.0001	0.001
	0.033)	0.026)	0.016)	0.019)	0.019)	0.018)	0.016)	0.008)	0.006)
FDI	1.546***	1.522***	1.489***	1.463***	1.443***	1.425***	1.404***	1.418***	1.388***
	0.052)	0.036)	0.029)	0.027)	0.023)	0.016)	0.020)	0.020)	0.027)
GDP	2.307***	2.289***	1.584***	1.454***	1.088***	1.059***	0.908***	0.704***	0.472**
	0.594)	0.545)	0.461)	0.427)	0.392)	0.328)	0.342)	0.205)	0.195)
RD	−0.388***	−0.398***	−0.402***	−0.374***	−0.371***	−0.364***	−0.327***	−0.340***	−0.339***
	0.040)	0.029)	0.021)	0.021)	0.017)	0.013)	0.014)	0.013)	0.011)
Panel C: independent variable: green investment									
Green_In	−0.0103	−0.0113*	−0.0123***	−0.0144***	−0.0133***	−0.095***	−0.013***	−0.081***	−0.04
	(0.064)	(0.061)	0.038)	(0.039)	0.034)	0.029)	0.026)	0.026)	0.026)
NFEC	−0.048	−0.015	−0.023	−0.043**	−0.053***	−0.058***	−0.061***	−0.067***	−0.055***
	(0.037)	(0.031)	0.019)	(0.021)	0.020)	0.018)	0.015)	0.015)	0.013)
EC	2.499**	1.747**	0.724	0.56	0.273	0.358	0.584*	0.207	0.283
	(0.976)	(0.847)	0.517)	(0.471)	0.380)	0.356)	0.337)	0.281)	0.298)
Trade	0.072**	0.027	0.033**	0.027	0.017	0.012	0.018	0.009	0.005
	(0.036)	(0.031)	0.016)	(0.020)	0.015)	0.014)	0.011)	0.009)	0.013)
FDI	1.611***	1.584***	1.570***	1.579***	1.553***	1.506***	1.487***	1.470***	1.430***
	(0.068)	(0.061)	0.035)	0.038)	0.031)	0.029)	0.025)	0.027)	0.033)
GDP	1.532*	1.26	0.789	0.06	0.147	0.559	0.067	0.35	0.071
	(0.921)	(0.810)	0.484)	0.546)	0.461)	0.430)	0.359)	0.279)	0.336)
RD	−0.401***	−0.398***	−0.390***	−0.373***	−0.356***	−0.344***	−0.333***	−0.334***	−0.356***
	(0.043)	(0.032)	0.019)	0.019)	0.018)	0.016)	0.015)	0.014)	0.010)
Panel D: independent variable: green security									
Green_Se	−0.0143	−0.0133*	−0.0125***	−0.015***	−0.033***	−0.089***	−0.015***	−0.097***	−0.014***
	(−0.054)	(−0.067)	(−0.047)	(−0.051)	(−0.034)	(−0.079)	(−0.056)	(−0.036)	(−0.039)
NFEC	−0.049	−0.048**	−0.052**	−0.072***	−0.069***	−0.070***	−0.080***	−0.080***	−0.071***
	(−0.039	(0.022)	(0.024)	(0.019)	(0.018)	(0.013)	(0.015)	(0.012)	(0.013)
EC	2.810***	1.886***	1.325**	0.638**	0.835*	0.843**	0.346	0.35	0.194
	(1.01)	(0.444)	(0.596)	(0.482)	(0.469)	(0.335)	(0.416)	(0.303)	(0.209)
Trade	0.083**	0.029	0.030*	0.038**	0.02	0.012	0.004	0.0005	0.002
	(0.036)	(0.024)	(0.017)	(0.019)	(0.019)	(0.017)	(0.016)	(0.006)	(0.009)
FDI	1.485***	1.508***	1.493***	1.466***	1.454***	1.439***	1.406***	1.417***	1.393***
	(0.052	(0.022)	(0.028)	(0.020)	(0.019)	(0.014)	(0.018)	(0.016)	(0.016)
GDP	2.276***	2.149***	1.597***	1.439***	1.157***	1.072***	0.925***	0.701***	0.468*
	(0.776)	(0.392)	(0.487)	(0.411)	(0.392)	(0.309)	(0.347)	(0.231)	(0.269)
RD	−0.375***	−0.397***	−0.406***	−0.374***	−0.371***	−0.362***	−0.326***	−0.341***	−0.339***
	(0.043)	(0.022)	(0.024)	(0.016)	(0.015)	(0.013)	(0.015)	(0.015)	(0.009)

Canay's model are aligned with the results of Powell's model, supporting our previous estimations shown in **Table 6**.

4.3.2 Different Alternative Measures

The alternative measures for the green finance index are considered to examine the robustness of results in this study, which uses three original variables as proxies for green finance, including green credit, green investment, and green securities. The results in **Table 7** show that three original variables, green credit, green investment, and green securities, basically presented the same negative significant effect on CO_2 emission as the GFI. In summary, various measures of green finance have had a significant impact on carbon dioxide emissions. Green finance improves environmental performance by reducing carbon dioxide emissions. Therefore, our results are reliable, and our main conclusions have not changed and the findings are robust.

5 CONCLUSIONS AND POLICY IMPLICATION

The study analyzes the relationship between green finance, non-fossil energy consumption, and CO_2 emission in BRICS. We used a fixed effect quantile regression on panel data between 2000 and 2018. We have developed an indicator of green finance based on

three sub-indicators—green credit, green investment, and green securities—to accurately measure green finance and precisely estimate its impact. The overall findings show the negative impact of green finance on CO_2 emissions in BRICS. However, the relationship between green finance and CO_2 emissions varies on different quantiles, even though the coefficient of green finance is not very encouraging. Furthermore, non-fossil energy consumption in BRICS has strongly mitigated carbon emission; however, its impact was short and discontinuous. Finally, CO_2 emission showed fluctuated results in the BRICS.

Based on the findings discussed above, we advocate designing a stable and continuous green finance policy because fluctuation in green policy negatively impacts CO_2 emissions and renewable energy production. Therefore, the stability and continuity of green finance stand out as a significant condition to maintain an effective emission reduction. Green finance in BRICS must be developed in its whole industrial chain. Furthermore, it should be implemented on a large scale to improve energy conservation. For that, the policy of green finance must be enhanced as follows:

1) Strengthening the legal supervision green finance system construction and implementing the suitable rules and regulations for such supervision. This system should include a full financial service related to green securities, green investment, green loans, and green bonds.
2) Financial authorities need to participate in the development of the carbon market through encouraging banks to introduce carbon emission rights in the pledge loans and provide a higher pledge rate within the risk-controllable range in the early stage of carbon finance. At the same time, they need to innovate carbon emission rights, finance products, and establish green channels for special approvals.
3) A green securities and bond rating system should be established that suits the national conditions of the BRICS economies. Before issuing green securities and bonds, an authoritative third party is required to verify whether these tools are indeed green and scientifically evaluate and measure the green benefits of the project. In addition, a team of experts should be formed who understand the value of green investment and can analyze and monitor the specific aspects of the funds used to support the green industry.
4) In order to achieve green landscaping that meets standards of energy-saving and to purchase green houses and new energy vehicles that meet the national building energy-saving certification, identify individual customers and provide special loans and support to small industries.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JH: conceptualization, ZX: data curation, JH: methodology and writing—original draft, and XW: data curation, visualization, review, and editing.

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Measuring Energy Efficiency Performance in China: Do Technological and Environmental Concerns Matter for Energy Efficiency?

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Considering the significance of green governance in economic restructuring and the green technology revolution, this study examines the impact of China's recent green governance policies and their implications in various regions; it also examines new models, methods, and development directions for China's green governance in the future. Green governance efficiency and spatial patterns have been studied through 2008–2018 data using a three-stage generalized panel Data Envelopment Analysis (DEA) model, spatial autocorrelation model, spatial gravity model, and social network analysis. The study summarizes the status and role of each provincial region in green governance based on the social network of green governance efficiency under the network architecture. It concludes that (1) green governance efficiency in China's provinces has a U-shaped trend, with non-managerial elements in the external environment masking genuine green governance efficiency. (2) During the study period, the overall efficiency of the industrial system improved. The efficiency of the manufacturing and wastewater stages has been substantially enhanced, but no significant gains were observed in the treatment stages of solid and gas waste. (3) Although China has made progress in enhancing the overall efficiency of its industrial system, there is still potential for improvement. (4) China has established a "three horizontal and two vertical grid-type" green governance spatial correlation structure among the sub-stages of the industrial system, and the radiation impact of major provincial areas would increase overall green governance efficiency.

Keywords: green governance efficiency, provincial, spatial pattern, generalized panel three-stage DEA, spatial effects

1 INTRODUCTION

China's 34.3% economy is accounted for by its industrial sector (Lee and Brahmasrene, 2020), which consumes 70% of the total energy in China, discharging 80% of its waste gases. To increase the use, treatment, and removal of industrial solid waste, sewage, and waste gases, the government of China is making significant efforts, and a detailed analysis of the past gains and losses regarding the industrial production and pollutants treatment performance of China provides a context for the adjustments

and improvements of the country's future policy (Wang and Feng, 2020). The literature highlights China's high energy-consuming and carbon-emitting industrial sector, focusing mainly on green productivity, energy, and the environment (Pastor et al., 2020). The industrial eco-efficiency for 2004 is examined through an input-oriented DEA (Data Envelopment Analysis) method, and only five provinces of China, out of 30, are found eco-efficient (Ding et al., 2020). Furthermore, the energy efficiency of the regional industrial sectors of China from 1997 to 2008 is investigated by a Malmquist index to find how an increase in the industrial energy efficiency of China is influenced mainly by technological progress (Simar and Wilson, 2019). Similarly, the sectorial environmental efficiency of China from 1998 to 2009 is studied through a non-radial DEA (Kang et al., 2018), which shows a 58% increase in the industrial environmental efficiency of the nation, considering technological progress as the main element. Moreover, green productivity in the industrial sectors of China from 1980 to 2010 is measured by applying a Luenberger index (Zhou et al., 2007), which shows a lack of a sustainable path producing low carbon growth (Bian et al., 2013).

Sustainable development is most likely achieved through a green economy playing the leading role (He et al., 2019). Hence, increased urbanization and industrialization caused a rise in the energy consumption of China, increasing pollution, which causes severe damage to the ecology (Mohsin et al., 2020b; Mohsin et al., 2018; Mohsin et al., 2021). Therefore, green economic development is deemed imperative, pertaining to the unfeasibility of the development model, where the environment is sacrificed to achieve economic benefits amid an economic transition. Moreover, the critical sustainable development measure is green governance efficiency (GGE), promoting economic growth and environmental development (Sueyoshi et al., 2017), which results in better economic growth with nominal environmental loss in limited resources. The economic growth quality, which adds to sustainable development worldwide, is revealed through a detailed GGE analysis of China (Mohsin et al., 2019; Mohsin et al., 2020a; Mohsin et al., 2021). Similarly, coal consumption in China records 52% of global CO_2 emissions, whereas 2013 recorded the peak for coal consumption and in 2014, it recorded 87.67% of China's energy consumption (Wu et al., 2020). Furthermore, China is recorded as the largest global carbon emitter in 2006 and the largest global energy consumer in 2010, exceedingly even the U.S., whereas 28% of global carbon emission is recorded in the present. Since 1998, 70% of the energy assumption in China is accounted for by coal consumption, summed up to 21% of global carbon emissions in 2017, regardless of its decrease since 2015 (Kozhakhmetova et al., 2019). Moreover, energy demand in China is considered the highest and is constantly increasing. Hence, with a relatively low ratio and nominal role of qualified energies, including petroleum and natural gas, the energy structure of China is coal-oriented as compared to the global average due to its natural resource distribution, "rich coal, meager petroleum and little gas" (Yuan et al., 2017; Hao et al., 2020). Similarly, the coefficient of coal for carbon emission is higher than petroleum or natural gas and, therefore, future economic and regional development in China depends on carbon emissions and air quality control due to the inability of the dominant position of coal within the Chinese energy structure to shift quickly (Musibau et al., 2021; Wu et al., 2021; Pavlyk, 2020).

Climate change and environmental protection is negatively affected by the energy price distortions due to the continuous increase in energy consumption for China (Yang et al., 2021; He et al., 2020; Mohsin et al., 2020b). Furthermore, misallocation and the consumption of threatened resources are caused by the distortion in energy prices, which does not suggest market values or the supply-demand balance. Moreover, China's economic development is promoted by artificially lowering energy prices, whereas distortions strengthen short-term resource concentration and production (Tavana et al., 2020; Ikram et al., 2019a; Sun et al., 2019; Ikram et al., 2019b), which reflects how administrative intervention causes a substandard economic growth due to the energy flows moving toward inefficient sectors rather than efficient ones. Energy price nexus mechanisms are examined in several previous studies, which do not consider the impact of energy price distortions on environmental and economic progress and their combined effect. Hence, this study focuses on GGE for China (Zhu et al., 2017) along with the influencing mechanisms. It also discusses the most widely consumed form of energy in China, which is fossil energy, the possible variation in the types of fossil energy, and how the GGE of different regions is affected, assisting policymakers in planning and achieving environmentally and economically balanced development by gaining a better grasp of the relation between energy price anomalies and GGE (Tavana et al., 2020).

Hence, this paper, (1) starts by measuring the efficiency of green governance in each region scientifically by building an evaluation index system, (2) followed by the clarification of the resource input adjustment mechanism of green governance on the basis of the redundancy analysis, ending with the clarification of spatial correlation for green governance in each region through the Moran index, the spatial gravity model, and the social network analysis method, respectively. Moreover, the efficiency of green governance is improved and the broad scope of green governance is expanded, radiating the periphery of spatial effect of green governance in the core region. The study also uses the three stage DEA model for the empirical assessment of Chinese provinces.

2 LITERATURE REVIEW

The DEA technique, a prominent mathematical model created by Charnes et al. (1978) and currently utilized to quantitatively assess sustainability-related concerns, is used to measure efficiency (Emrouznejad et al., 2010). DMUs are always a "black box" in classic DEA models, regardless of the DMUs, including a two-stage network. Scholars have built substantial network-based DEA models to analyze the effectiveness of environmental decentralization. Energy effectiveness is calculated using a variety of predictors (Sun et al., 2020a; Baloch et al., 2020), with single factor and total factor energy efficiency being the most commonly used indicators (Omrani et al., 2021). **Figure 1** shows Green governance efficiency by first stage generalized-panel DEA (before adjustment).

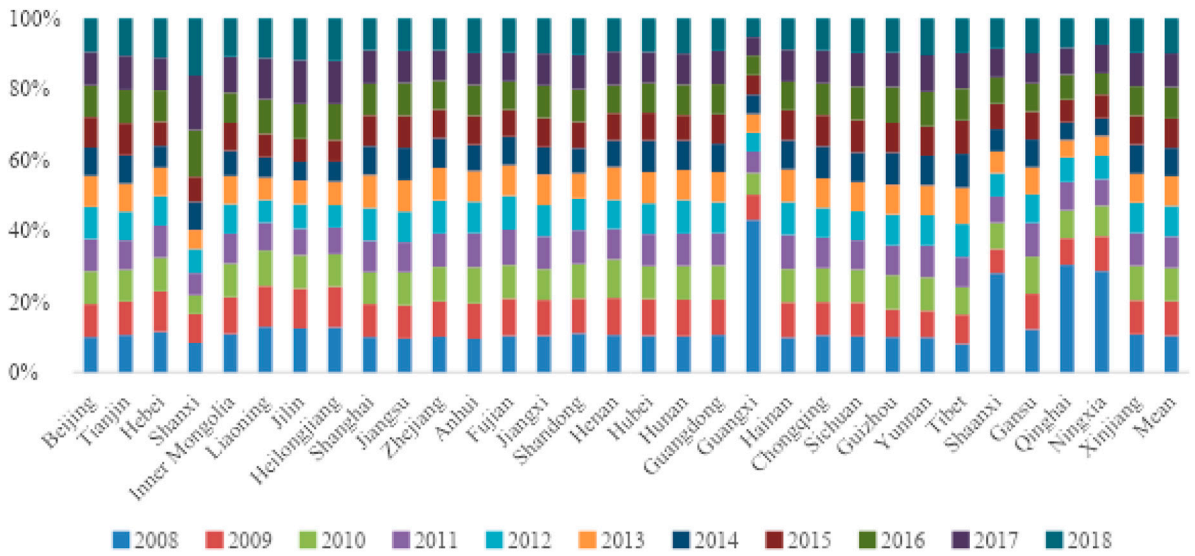

FIGURE 1 | Green governance efficiency by first stage generalized-panel DEA (before adjustment).

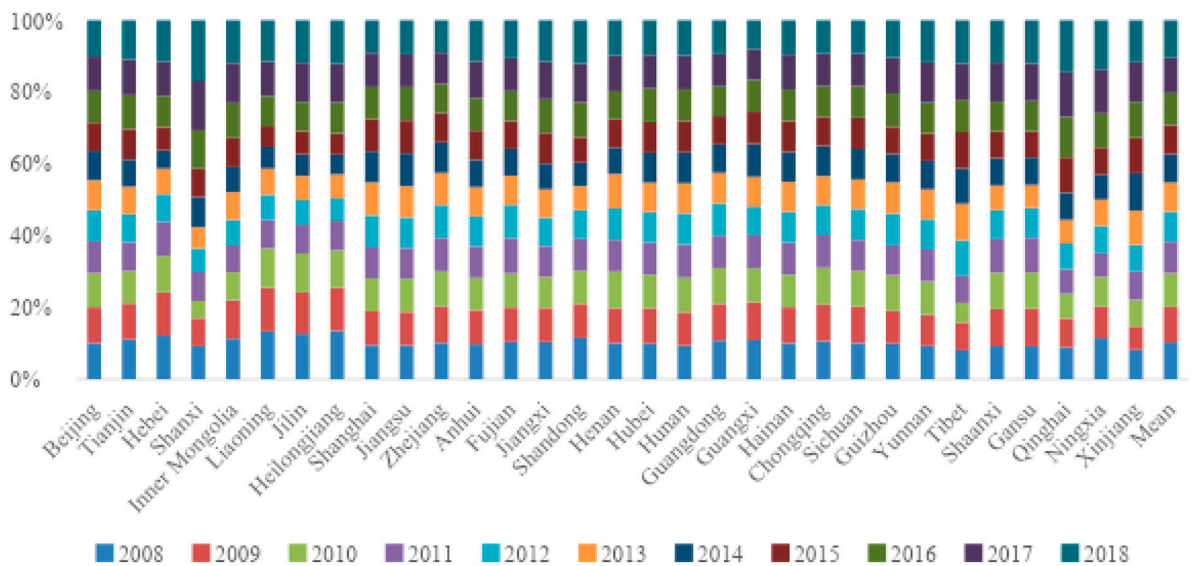

FIGURE 2 | Green governance efficiency by the first stage generalized-panel DEA (after adjustment).

Figure 2 states the Green governance efficiency by first stage generalized-panel DEA (after adjustment). GE is studied by a number of existing studies and the evaluation indicator system (OECD, 2011) and efficiency evaluation methods are the two main approaches used to measure efficiency. Moreover, parameter-based stochastic Frontier analysis (SFA) and the nonparametric data envelopment analysis (DEA) approach are the two main types of efficiency methods. The eco-efficiency of major world economies is measured through the SFA and DEA methods, which measure the efficiency of a decision-making unit with inputs and outputs objectively as compared to the subjective indicators of weighting involving the high degree of uncertainty in the evaluation results (Kortelainen, 2008; Halkos and Petrou, 2019). Hence, the SFA approach is not applicable to quantifications with multiple inputs and outputs and requires specified production function (Zhou et al., 2013). Some scholars believe in how the production costs of a country are increased by environmental regulation while weakening the competition of enterprises (Nasawat et al., 2021; Emrouznejad and Yang, 2018; Yeşilyurt et al., 2020). Furthermore, when it comes to research

methodology, the majority of past studies use linear analysis and static research (Sun et al., 2020b; Sun et al., 2020; Sun et al., 2020a). Hence, it is impossible to solve the endogeneity problems and ordinary panel data estimates in the related studies.

Eco-efficiency is described as a single process in the previous studies focusing on the industrial sector, overlooking the essential role of the government, generating CO_2 emissions directly. Furthermore, the government sector offers important services, but the precise effects of the government sector on the industrial sector or even overall efficiency (eco-efficiency) are unknown. The sectoral correlations and interactions within China's GGE are not considered in the evaluation of this study, omitting target sectors for policy governance.

3 RESEARCH METHODOLOGY AND DATA SOURCES

3.1 Research Methodology

3.1.1 Data Envelopment Analysis

Furthermore, authorities and universities are emphasizing energy efficiency in terms of growing concerns about global warming, fast development in energy needs, and poor energy safety (Wu et al., 2020). However, unwanted outputs like the discharge of wastewater, exhaust emissions, and waste production are not considered when current energy efficiency indices are calculated. Hence, this study builds an index for energy efficiency called green governance efficiency (GGE), which considers the undesirable output and follows the concepts of sustainable growth from earlier literature. Therefore, it is challenging to determine whether the angular and radial measures as a traditional DEA model starts with input or output. As a result, the fraction of all input (outcomes and impacts) decreased (raised) in an equal proportion is included in the calculation of inefficiency.

Similarly, in faulty decision-making units where the percentage change is not equal to the actual input-output, the relaxation improvement, omitting the equal proportion development element, is not discovered by the quality evaluation of the standard DEA model. Therefore, Slacks-based measure (SBM) models (non-radial and non-angular) are derived by Tone (2001) by proposing relaxation variables directly into the objective function, which also overlooks the influence due to the selection of the radial and the angular systems, measuring the inefficiency situation through the input and output angles. Hence, the external adverse environmental effects resulting from the manufacturing process are ignored, and the output of the standard SBM model is set to the expected output. The input-oriented variable returns to scale DEA model, and this paper chooses the generalized BBC-DEA model, considering the existence of input controllability of green governance. If n is the number of decision-making units (DMUs) and the individual DMU $\bar{n}$ sample units (SU) at$t$ time periods is given as $\bar{n} = nt$, the following equations represent the model as

$$
\begin{aligned}
MaxE_k^* = & \sum_{d=1}^{D} w_d z_{dk} + \sum_{P=1}^{P} \varpi_p M_{pk} \\
& + \sum_{r=1}^{s} u_r y_{rk} s.t \Big\{ \sum_{i=1}^{m} v_i x_{ik} + \sum_{d=1}^{D} w_d z_{dk} + \sum_{P=1}^{P} \varpi_p M_{pk} = 1 \\
& \sum_{d=1}^{D} w_d z_{dj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, j = 1, 2, \cdots, n \\
& \sum_{p=1}^{P} \varpi_p M_{pj} - \sum_{d=1}^{D} w_d z_{dj} \le 0, j = 1, 2, \cdots, n \\
& \sum_{r=1}^{s} u_r y_{rj} - \sum_{p=1}^{P} \varpi_p M_{pj} \le 0, j = 1, 2, \cdots, n \\
& w_d \geqslant \varepsilon, d = 1, 2, \cdots, D; \varpi_p \ge \varepsilon, p = 1, 2, \cdots, P \\
& u_r \geqslant \varepsilon, r = 1, 2, \cdots, s; v_i \ge \varepsilon, i = 1, 2, \cdots, m
\end{aligned} \tag{1}
$$

where each DMU shows m inputs and s outputs, x_{ip} is the i input of the p decision unit andy_{rp} is the output of r. Here, $\bar{x}_{ij}$ is the i input of the$j$ sample cell and $\bar{y}_{rj}$ is the output of r. Similarly, the efficiency value to be evaluated is given as $\theta_p$and slack variables for the input and output indicators are given as S_{ip}^- and S_{rp}^+. The progress of the system is characterized by a mobility factor d and a non-Archimedean infinitesimal is given as ε, whereas the weighting variable is represented as λ_j.

3.1.1.1 Step2 SFA Model Adjustment

A nonparametric method called DEA, commonly used to quantify eco-efficiency, is used to evaluate the efficiency of decision-making units (DMUs) that can consume numerous inputs and generate multiple outputs (Zhou et al., 2008). Long et al. (2017) evaluated the eco-efficiency of cement manufacturers in China and found a converging tendency in the Eastern, Central, and Western regions. Furthermore, DEA was used to assess the eco-efficiency of China's industrial sector by Yang et al. (2017), Zhang et al. (2017). The Data envelopment analysis have been used to measure the green governance efficiency analysis where as the regression model is used to access the impact of non managerial concerns.

$$
\begin{aligned}
MaxE_k^1 = & \sum_{d=1}^{D} w_d z_{dk} \, s.t. \Big\{ \sum_{i=1}^{m} v_i x_{ik} = 1 \\
& \sum_{d=1}^{D} w_d z_{dj} - \sum_{i=1}^{m} v_i x_{ij} \le 0, j = 1, 2, \cdots, n \\
& v_i \ge \varepsilon, i = 1, 2, \cdots, m \\
& w_d \ge \varepsilon, d = 1, 2, \cdots, D
\end{aligned} \tag{2}
$$

where S_{ij}^- is the i input relaxation variable for the$j$ sample cell, W_d represent the K environmental variables, vx_i is the vector of parameters to be estimated for the environmental variables, whereas random disturbance and management noise, independent of each other, are represented by v_{ij} , u_{ij}. Similarly, the corrective adjustment formula of the original inputs through SFA regression model is given as, where x_{ij}^A represents the adjusted input value, represents the adjustment for environmental factors, whereas $\max_i v_{ij} - v_{ij}$is the adjustment for random disturbances.

The adjusted green governance efficiency value θ_j for each province is obtained by substituting the adjusted input variables from **Equation**(3) with model (1). Hence, the

optimal input is clarified, comparing the actual input to achieve input redundancy value through the analysis of the efficiency Frontier surface. Therefore, the direction of the improvement of input variables is confirmed through the projection analysis of the input variables and the following DEA projection formula is used to obtain the i optimal input value $\hat{x}_{ij}$ for the j sample cell. Li Wei'an's is used to improve the basis of this research. **Table 1** shows the details. This study measures China's total-factor efficacy of energy under environmental constraint by selecting panel data from 31 provinces with a three-stage DEA model, where the inputs, desirable outputs, and undesirable production are included in the model. The three given variables, including labor (L), capital stock (K), and energy utilization (EU) are represented by the input division. The gross domestic product (GDP) is considered as the desired output, whereas as unwanted output variables, wastewater discharge (WW), exhaust gas emission (WG), and solid waste creation (WS).

3.1.2 Econometric Analysis

An effective combination of the first law of geography and econometrics is obtained by the global spatial autocorrelation analysis, based on the exploratory analysis of spatial data, which explores a spatial unit for the degree of clustering and interaction of some aspects within it. The calculation formula is given as:

$$I = \frac{N}{\sum_i W \sum_j W_{ij}} \frac{\sum_i W \sum_j jW_{ij}(Z_i - \mu)(Z_j - \mu)}{\sum_j j(Z_i - \mu)^2} \tag{3}$$

where the number of provinces is identified as n, the green governance efficiency values of the two provinces as x_i and x_j, and the specific element of the spatial weight matrix W as W_{ij}. Moran's, I index rages from (−1, 1), whereas with calculated value greater than 0, a positive spatial correlation between green governance in each province is identified, showing a robust spatial clustering feature with an increase in the value becoming more significant. Similarly, with calculated value less than 0, a negative spatial correlation between green governance in each province is evident, whereas the significance increases showing a high degree of spatial variation. The absence of spatial interaction and clustering correlation shows green governance in each province distributed in a random style.

3.1.3 Space Gravity Model

This study determines the potential interaction between green governance in each province through spatial autocorrelation analysis; however, feedback on the scale of association and gravitational agents in the interaction process is absent. Moreover, this study determines the degree of interaction between green governance in different provinces by building

TABLE 1 | Green governance efficiency by first stage generalized-panel DEA (before adjustment).

Province	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Beijing	1.00	0.93	0.92	0.91	0.91	0.88	0.80	0.87	0.90	0.95	0.95
Tianjin	0.84	0.75	0.71	0.66	0.64	0.63	0.64	0.73	0.75	0.77	0.83
Hebei	0.54	0.54	0.45	0.43	0.39	0.38	0.29	0.32	0.42	0.43	0.52
Shanxi	0.23	0.23	0.15	0.17	0.19	0.15	0.22	0.20	0.37	0.44	0.46
Inner Mongolia	0.32	0.30	0.28	0.25	0.24	0.23	0.21	0.23	0.25	0.30	0.32
Liaoning	0.41	0.37	0.32	0.25	0.21	0.20	0.18	0.21	0.31	0.38	0.36
Jilin	0.40	0.37	0.30	0.24	0.22	0.22	0.17	0.21	0.32	0.40	0.38
Heilongjiang	0.39	0.35	0.28	0.23	0.19	0.20	0.17	0.19	0.31	0.37	0.37
Shanghai	1.00	0.93	0.89	0.89	0.93	0.94	0.82	0.87	0.90	0.95	0.90
Jiangsu	0.89	0.88	0.87	0.80	0.81	0.83	0.86	0.85	0.87	0.85	0.86
Zhejiang	0.91	0.90	0.88	0.86	0.84	0.83	0.76	0.73	0.74	0.78	0.81
Anhui	0.64	0.67	0.69	0.65	0.60	0.58	0.50	0.55	0.59	0.61	0.65
Fujian	0.71	0.72	0.65	0.69	0.66	0.60	0.55	0.52	0.55	0.56	0.66
Jiangxi	0.64	0.63	0.54	0.58	0.55	0.54	0.48	0.52	0.57	0.57	0.62
Shandong	0.68	0.61	0.60	0.59	0.55	0.44	0.44	0.45	0.57	0.60	0.64
Henan	0.55	0.54	0.56	0.45	0.43	0.48	0.39	0.40	0.41	0.50	0.48
Hubei	0.66	0.67	0.59	0.58	0.56	0.57	0.58	0.50	0.54	0.57	0.61
Hunan	0.60	0.61	0.56	0.54	0.56	0.50	0.50	0.43	0.51	0.52	0.59
Guangdong	0.98	0.92	0.89	0.85	0.82	0.78	0.75	0.77	0.80	0.87	0.85
Guangxi	1.00	0.16	0.14	0.14	0.12	0.12	0.13	0.13	0.13	0.12	0.12
Hainan	0.73	0.74	0.69	0.72	0.69	0.68	0.62	0.63	0.60	0.68	0.65
Chongqing	0.98	0.88	0.89	0.82	0.78	0.78	0.85	0.82	0.84	0.87	0.85
Sichuan	0.88	0.83	0.80	0.72	0.71	0.72	0.73	0.80	0.82	0.83	0.84
Guizhou	0.40	0.32	0.39	0.34	0.35	0.34	0.37	0.34	0.41	0.39	0.39
Yunnan	0.39	0.30	0.37	0.36	0.34	0.34	0.33	0.33	0.39	0.41	0.41
Tibet	0.62	0.64	0.60	0.66	0.72	0.78	0.74	0.73	0.70	0.77	0.75
Shaanxi	1.00	0.24	0.27	0.26	0.24	0.22	0.23	0.25	0.27	0.29	0.31
Gansu	0.24	0.20	0.20	0.19	0.16	0.15	0.15	0.15	0.16	0.17	0.19
Qinghai	1.00	0.25	0.26	0.26	0.23	0.16	0.17	0.21	0.23	0.25	0.27
Ningxia	1.00	0.34	0.30	0.26	0.23	0.20	0.18	0.24	0.21	0.28	0.26
Xinjiang	0.68	0.61	0.61	0.59	0.55	0.52	0.52	0.52	0.53	0.60	0.62
Mean	0.59	0.56	0.54	0.51	0.50	0.48	0.46	0.47	0.51	0.55	0.57

and modifying the spatial gravity model. Where the degree of spatial correlation of green governance efficiency between the two provinces is given as R_{ij}, the spatial gravity coefficient as M_{ij}, the green governance efficiency of province i and province j as S_i and S_j, the spatial distance between the two regions as D_{ij} and the size of green industries and GDP per capita of each province as Z and g. Moreover, the total spatial association of green governance in region i to measure the extent of effect for green governance efficiency in region i on other regions is characterized as A_i.

3.2 Data Sources

This study considers the data availability and analytical value for 31 provinces in China for the period 2008–2018 and the data is obtained from the *China Science and Technology Statistical Yearbook*, *China High Technology Industry Statistical Yearbook*, *China Statistical Yearbook*, *Provincial and Municipal Statistical Yearbooks*, *EPS Data Platform*, and the patent search and analysis system of the *National Intellectual Property Office*. Hence, green innovation identifies with high technology driving sustainable development in society, considering the meaning of green in the green governance indicator system along with green innovation as an external manifestation of green governance. Consequently, the raw data for core content of green governance and green innovation is reprocessed in this section, specifically the research and development institutions for local (government) departments in the high-tech industry, the number of employed research and development personnel, the money spent on R&D, innovation projects completed or in-progress along with the new fixed asset investment in innovation applied to clarify the meaning of "green".

4 RESULTS AND DISCUSSION

4.1 Green Governance Efficiency in China

Furthermore, there is variation in the four regions for long-term trends and the effectiveness between both sectors, with an increase of 111.11% in the Eastern part of the country for governance performance, rising from 0.27 in 2007 to 0.57 in 2015, whereas the industrial sector's efficiency rose by 77.63% during the study period. **Table 2** shows green governance efficiency scores. The economic and environmental efficiency scores of the Chinese provinces reflect that environmental efficiency shall be measured by fixing the best undesirable output, which generates a green governance efficiency score. It can be seen that most countries have higher economic efficiency scores than environmental efficiency, which means that these countries are economically and environmentally efficient. Shanxi and Inner Magnolia are the least efficient countries with scores below 1.

The external environment is seen to influence green governance more after eliminating factors, such as management noise, external environment, and random error as shown in **Table 2**, where the green governance efficiency fluctuates more in the first and third stages.

The period 2008–2014 for the eve of launch for green governance strategy comes under the first cycle which scatters the activities related to green governance in each region, whereas the respective planning and location conditions determine the development of relevant governance strategies. Similarly, the formal introduction of green governance for the period of 2015–2018 is included in the second cycle which shows a positive interoperability, a high degree of unity and close connection for green governance in all regions. The previous period shows increase of approximately 4.12% with the average value of green governance efficiency for each province in the current period reaching 0.480, as shown in **Table 2**.

Furthermore, the Western area increased from 0.13 in 2009 to 0.36 in 2014, before declining after 2014, the production activities of industrial sectors showing a negative trend. As a result, the utilization of fiscal income after 2014 reveals a relatively poor quality with a falling tendency, whereas natural resource rent is a significant source of revenue for resource-based towns. Furthermore, the abundance of natural resources has a detrimental impact on the government, resulting in rent-seeking activities that squander money and lead to corruption. Consequently, the unsustainable development of resource-based areas may occur due to the inefficiency of the government sector resulting in institutional weakening.

4.2 Econometric Estimation of External Environment and Green Governance Efficiency

This paper uses an econometric prediction model to calculate **Equation (3)** in the methodology and considers the possible endogeneity between environmental laws predictors and GGE, conducting the estimations through generalized moment estimation and strengthening the estimated results. Furthermore, the Hansen test and the autoregressive AR2 estimate results show no second-order sequence correlation. Similarly, GGE is "U-shaped," with an increase in environmental regulation inhibiting GGE improvement before the level of environmental law reaching its defining moment. In contrast, an increased environmental process law can increase GGE advancement.

As a result, the regression findings are compressed by the "cost" of complying with environmental regulations, and the increase of green total factor productivity is stifled, making it impossible to motivate businesses to do technical R&D in the short term. Similarly, it also reduces pollution through changed production methods, improving the green total factor productivity simultaneously. Consequently, the market concentration is further increased due to the market's withdrawal through some high-energy enterprises and strict environmental regulations. In contrast, retained enterprises improve the core competitiveness, promoting green total-factor long-run efficiency by focusing on green technology innovation. Nevertheless, green institutions and personnel under the leadership of social organizations do not follow the macro policy direction of the government due to the excessive financial, environmental investment, leading to redundancy in the allocation of government organizations through the disincentive effect under the regulation of the market.

TABLE 2 | Green governance efficiency by first stage generalized-panel DEA (after adjustment).

Province	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Beijing	0.95	0.95	0.90	0.86	0.82	0.80	0.78	0.75	0.84	0.92	0.95
Tianjin	0.85	0.78	0.70	0.62	0.60	0.59	0.59	0.66	0.74	0.77	0.84
Hebei	0.54	0.54	0.46	0.43	0.35	0.32	0.23	0.29	0.39	0.43	0.51
Shanxi	0.25	0.21	0.13	0.21	0.18	0.16	0.23	0.21	0.29	0.37	0.45
Inner Mongolia	0.33	0.31	0.23	0.22	0.21	0.22	0.20	0.24	0.28	0.33	0.35
Liaoning	0.42	0.39	0.35	0.26	0.22	0.23	0.20	0.18	0.27	0.31	0.37
Jilin	0.40	0.37	0.34	0.25	0.22	0.21	0.19	0.20	0.26	0.35	0.37
Heilongjiang	0.38	0.34	0.30	0.23	0.18	0.19	0.16	0.17	0.25	0.31	0.34
Shanghai	0.97	0.96	0.93	0.88	0.91	0.93	0.89	0.90	0.92	0.97	0.91
Jiangsu	0.91	0.90	0.89	0.82	0.83	0.84	0.89	0.88	0.90	0.89	0.90
Zhejiang	0.94	0.94	0.90	0.87	0.85	0.83	0.79	0.75	0.77	0.80	0.83
Anhui	0.60	0.59	0.56	0.54	0.52	0.51	0.47	0.51	0.57	0.64	0.71
Fujian	0.69	0.64	0.63	0.66	0.62	0.54	0.50	0.51	0.56	0.61	0.70
Jiangxi	0.61	0.55	0.51	0.50	0.46	0.46	0.42	0.50	0.55	0.62	0.67
Shandong	0.66	0.55	0.53	0.52	0.46	0.39	0.38	0.41	0.56	0.63	0.69
Henan	0.51	0.50	0.52	0.46	0.45	0.49	0.38	0.40	0.41	0.51	0.50
Hubei	0.71	0.71	0.68	0.64	0.61	0.59	0.60	0.62	0.67	0.68	0.69
Hunan	0.63	0.63	0.64	0.62	0.59	0.56	0.58	0.59	0.60	0.63	0.66
Guangdong	0.97	0.92	0.90	0.82	0.81	0.77	0.72	0.72	0.74	0.82	0.84
Guangxi	0.17	0.16	0.15	0.14	0.12	0.13	0.14	0.14	0.14	0.13	0.12
Hainan	0.71	0.70	0.65	0.63	0.60	0.60	0.59	0.61	0.63	0.68	0.67
Chongqing	0.95	0.90	0.92	0.81	0.75	0.72	0.75	0.72	0.76	0.82	0.82
Sichuan	0.84	0.86	0.83	0.73	0.72	0.70	0.71	0.73	0.74	0.76	0.77
Guizhou	0.40	0.37	0.40	0.34	0.35	0.35	0.32	0.30	0.38	0.40	0.42
Yunnan	0.35	0.33	0.35	0.34	0.32	0.32	0.30	0.29	0.33	0.43	0.44
Tibet	0.12	0.11	0.08	0.11	0.14	0.15	0.14	0.14	0.13	0.15	0.17
Shaanxi	0.24	0.27	0.27	0.25	0.21	0.18	0.20	0.20	0.22	0.29	0.31
Gansu	0.23	0.26	0.25	0.25	0.21	0.16	0.19	0.18	0.22	0.27	0.30
Qinghai	0.18	0.16	0.14	0.14	0.14	0.13	0.15	0.20	0.23	0.25	0.29
Ningxia	0.21	0.16	0.15	0.12	0.14	0.13	0.12	0.14	0.17	0.22	0.25
Xinjiang	0.15	0.12	0.14	0.15	0.14	0.18	0.20	0.19	0.19	0.21	0.22
Mean	0.54	0.52	0.50	0.47	0.44	0.43	0.42	0.43	0.47	0.52	0.55

4.3 Projection Analysis of Green Governance Efficiency in China

A noticeable rise in government sector efficiency in the Western area, from 0.13 in 2009 to 0.36 in 2014, is shown with a drop, a tendency also apparent in China. This downward trend reflects the government sector's generally low quality in its use of fiscal revenue after 2014. Natural resource rent may be highly beneficial to resource-based towns.

The different trends based on the geographical location and economic development are seen in the data analysis in **Table 3**, reflecting redundancy in green governance inputs in all the provinces and aspects of China. Hence, with an average of 52.129%, an enormous redundancy scale is found in green organizational building capacity, which shows the least redundancy with 52.129% as an average. Similarly, green investment capability shows the least redundancy with an average redundancy of 40.601%, whereas the average redundancy of 42.111, 42.408, and 42.451% is found for green organizational configurations capability, green service capability, and green operations capability. This reflects the industrial sector's more efficient manufacturing actions as a result of the public sector's higher efficiency and the linking structure's ability to influence the flow of intermediates, such as facilities, new tech, schooling, and health, and thus affect production operations, which is the reason for this positive relationship.

Hence, the provinces of China show industrial system efficiencies of significant differences and a value of more than 0.9 is recorded for the GGE of Shanxi, Jilin, Jiangsu, Zhejiang, Anhui, Fujian, the Xinjiang's total factor productivity and wastewater governance efficiencies, and Tianjin's solid waste governance efficiencies all need to be improved. Hence, steps should be taken to improve the performance of industry system by clarifying the efficiency-related performance of the sub-stages in Chinese provinces.

4.4 Spatial Structure Analysis of Provincial Green Governance Efficiency in China

The average efficiency of the government sector and production efficiency are both 0.42, with Shaoyang (0.87) and Xuzhou (0.80) ranking first and second, respectively. Similarly, Shaoyang (1.00) and Xuzhou (1.00) are the highest performers in production efficiency, suggesting that they have the best-practice technological frontier with sectoral efficiencies of 1.00 (**Table 4**).

The clock is ticking, the snow on the glaciers is melting, and the sea level is rising. People are dying due to floods, droughts, heat strokes, and natural catastrophes. China is currently

TABLE 3 | Econometric estimation of redundancy of green governance (role of technology).

Variables	OLS	FE	RE	SYS-GMM	SYS-GMM
GGEit-1	—	—	—	—	0.859***
—	—	—	—	—	(−46.356)
ER	−0.062***	−0.132***	−0.125***	−0.243***	−0.069***
—	(−2.442)	(−3.452)	(−4.106)	(−5.250)	(−3.443)
ED	0.013***	0.051***	0.038***	0.139***	0.031***
—	(−2.342)	(−3.551)	(−3.564)	(−3.594)	(−3.433)
FDI	−0.351***	−0.211	−0.102	0.03	0.043
—	(−2.1222)	(−1.445)	(−0.643)	(−0.163)	(−0.543)
Infra	0.048**	−0.001	0.021	0.122***	0.043***
—	(−3.301)	(−0.044)	(−1.135)	(−7.336)	(−9.54)
PGDP	0.037***	0.010***	0.011***	0.009***	0.012***
—	(−11.231)	(−4.093)	(−3.445)	(−3.008)	(−2.234)
INDSTR	0.411***	0.255***	0.255***	0.076	0.042**
—	(−5.432)	(−3.371)	(−3.556)	(−1.232)	(−1.663)
R&D Inten	0.044***	0.022***	0.029***	0.051***	−0.012
—	(−2.542)	(−3.611)	(−4.653)	(−10.883)	(−1.121)
_cons	0.067	0.424***	0.389***	0.478***	0.041***
—	−1.221	−12.476	−10.165	−9.967	−3.332
R2	0.1122	0.3228	0.3184	—	—
AR (2)	—	—	—	1.66*	1.12
—	—	—	—	(0.087)	(0.332)
Hansen test	—	—	—	19.93	19.58
—	—	—	—	(1.011)	(0.332)
F/Wald test	166.21***	21.10***	154.18***	1,432.53***	321,111.33***
N	320	360	360	330	330

*Note: ***, **, and * indicates statistical significance at the 1, 5, and 10% levels, respectively, and the* p*-values of the associated test statistics are shown in ( ).*

experiencing a threefold increase in heat compared to the worldwide rate at the same time, the temperature has risen by more than 2°, which has been melting the glaciers and the impact can be seen in the form of pulverized homes, dangerous food insecurities, and ravenous animals, for instance polar bears. In Japan, heavy rains in 2018 initiated landslides and floods, which killed around 200 people (Hao et al., 2021). In addition, the indescribable heat waves endangered the vulnerable species in the region. The climate has been getting worse, a pattern of abnormal weather will start occurring more than before, while the region will consume double as compared to the present consumption (Halicioglu and Ketenci, 2018).

The green governance in all provinces shows a significant upward trend as seen in, whereas the position and role of each province in the social network of green governance are comparatively solidified due to factors such as simultaneous increases and slight differences in the magnitude of the increases. Furthermore, between 2004 and 2015.

Figure 3 shows the green redundancy. We found that the green governance in all provinces shows a significant upward trend as seen in Table 8, whereas the position and role of each province in the social network of green governance are comparatively solidified due to factors, such as simultaneous increases and slight differences in the magnitude of the increases. Furthermore, between 2004 and 2015. Result shows that, the 1% significance analysis results in an extraordinary two-way influence (2). Within the constant 96 percent confidence level shown in **Table 5**, the approximate upper limits are 0.763 and 0.833 and (0.801), (3.863), and (0.763, 3.861).

This fact indicates that energy-focused technology advancements have a non-linear influence on EE, with a maximum value of 61.33. This means that the influence of advancements in energy-oriented technology on EE is variable, both above and below the upper limit amount. Results illustrates the regional green economic performance stage concerning the upper limit values. In 3010 and 3017, respectively, the EPI of around 0.301 increased by 63.3% and 86.3%. Similarly, regions with EPI values between 0.301 and 0.738 increased by 3.3% and 33.6%, respectively, demonstrating these regions' green economic success during the research period. Regions with a larger than 0.738 economic performance index have a similar consistent expansion trend. This trend results from economic improvements taking root at the province level of around 9.7% and 16.1%, respectively, and provincial creative systems continuing to reach new heights, (**Table 6**) economic performance coupled with the green economic performance was above 0.73 altered after 2013.

Nevertheless, provincial performance in combination with green economic performance was more than 0.73 following 2013. Between 2010 and 2017, provinces with an economic progress level greater than 0.738 decreased from roughly 90.3 to 83.9 percent. Provincial technology improvements have a direct effect on the viability of the country's regional economies. The percentage of provinces where provincial technical breakthroughs had a tangible effect on promoting sustainable development decreased from 87.1 to 61.3 percent within the research period. Additionally, the proportion of provinces where provincial technical breakthroughs had a negligible influence on sustained provincial progress increased from 3.3 to 33.6 percent throughout the research period. As a

TABLE 4 | SFA regression model results.

	Green-organizational-	Configurations-capability	Green-investment-capability	Green-service-capability
Constant	−174.242***	−629.553	−4,346.153	−41.665
Economic environment	−2.145	−5.886	−41.443	41.553***
Technical environment	−0.665	−19.764	−31.774	−39.332
Financial environment	2.135***	4.211**	−29.343	−15.552
Sigma-squared	7,354.334***	315,332.122***	1,685,432.1***	17,764.32 ***
Gamma	0.872***	0.771***	0.882***	0.994***
Log-L	−1,227.772	−2,664.224	−3,675.77	−31667.554
LR	347.155	623.556	334.566	299.887

*Note: ***, **, * indicate* t*-values significant at the 1, 5 and 10% significance levels respectively.*

FIGURE 3 | Green redundancy.

TABLE 5 | Results of the threshold test.

	Threshold test	F-value	*p*-value	Critical value		
				1%	6%	10%
Model 1	Single	78.677***	0.000	33.333	13.773	10.332
	Double	31.333***	0.006	33.666	13.333	10.773
Model 2	Single	61.333***	0.000	33.673	13.331	10.663
	Double	39.333***	0.001	3.666	−7.775	−11.773

TABLE 6 | Estimated threshold variables.

Threshold variables	—	Estimated thresholds	96% confidence interval
Model 1	$\gamma 1$	0.338	(0.190, 3.661)
	γ_3	0.733	(0.661, 3.663)
Model 2	γ_1	0.673	(0.773, 3.269)
	γ_3	0.771	(0.663, 3.331)

result, one may argue that China's current atmosphere is progressive in general.

5 CONCLUSIONS AND POLICY IMPLICATION

This research creates a generalized panel three-stage DEA model on the concept of green governance to objectively measure, assess, and evaluate the efficiency of 31 provinces in China in the period 2008 to 2018. Through an external environment and projection analysis, it highlights the direction of green governance efficiency improvement. The intrinsic geographical correlation and magnitude of spatial connection of green governance effectiveness in Chinese provinces are revealed using this research's spatial autocorrelation model, spatial gravity model, and social network analysis.

1) There is a clear correlation between governance and production efficiency. The resource-based cities in the Central, Western, and Northeast regions should be given special attention, as their governance and production efficiency deteriorated after 2014. This pattern demonstrates the government sector's low quality in fiscal income derived from natural resource rents. According to the projection analysis of green governance input redundancy, the redundancy of each input element is more severe, and the problem of internal variation in redundancy is apparent. Although China has achieved some initial success in enhancing the overall efficiency of its industrial system, more progress is required.
2) China has two development cycles of provincial green governance efficiency, with 2015 serving as an inflection point with U-shaped change characteristics in terms of the temporal dimension. The official implementation of several techniques, such as green governance, has resulted in a consistent and high-quality improvement in green governance efficiency. All input redundancies are harmed by the technology environment, implying that the technology market is the ultimate goal of green governance and a critical position to enhance resource use efficiency and

remove input redundancies. The redundancy of green organizational building capacity and green organizational configurations capacity has a significant beneficial association with the economic environment, but it can absorb the redundancy of green investment capability, green service capability, and green operations capacity positively. The use of the market to manage the complementary roles of social and financial capital becomes a vital component of the optimal regulation of green governance efficiency.

3) Between 2004 and 2015, China's industrial efficiency increased substantially. Specifically, the efficiency of the production and wastewater sub-stages has substantially increased, but the efficiency of the solid waste and waste gas treatment sub-stages has not improved significantly. Significant results show as a correlation between GDP growth and GHG emission. (It caused an increase of GHG releases, i.e., emissions with the perspective of Canada due to growth in GDP.) The corresponding growth in gross domestic product, i.e., GDP due to swings in economic movement showed significant and positive impacts on GHG releases, i.e., emissions. Whereas other side nations who utilize greater energy also experience challenges of energy security and greater volume GHG emissions per capita. Results indicate that in both well-developed and welfare nation's fossil fuels subsidies caused a greater energy utilizing nations experience and face challenges of greater GHG releases, i.e., emissions and energy security per capita. Furthermore, different research studies also show that both well-developed and welfare nations caused a greater volume of using fossil fuels. Because of the increasing trend toward the utilization of renewable energy, similar strategies are being depressed. Reduction in subsidy is forecasted in Australia to decrease GHG releases, i.e., emissions by the year 2030 will be 12%. GHG values demonstrate the energy being utilized in those nations is typically being generated from the sources of fossil fuel. Conversely, those nations experiencing the lowermost GHG have greater energy of renewable utilization, for instance, Iceland has 77.03% renewable energy; it also has GHG releases, emissions per unit utilization of energy.

5.1 Policy Implication

The following policy implications can be taken from the preceding findings.

China's market-based energy market process will be refined, and a comprehensive and uniform energy pricing system will be established. Unless an efficient reformed energy pricing system is in place, energy price anomalies cannot be removed, and excessive carbon emissions and power consumption cannot be managed, all at the expense of GEE progress. Furthermore, because different fossil fuel costs are not consistently marketized, the prospect of replacing clean energy with low-cost, high-polluting alternatives is increasing. As a result, the government should focus on reforming the oil and natural gas pricing, which are now inadequately market-oriented. Energy price changes must be implemented at all levels to create a complete and consistent pricing structure.

Diverse energy pricing strategies for different regions should be implemented. Attempts to reduce the outflow of local energy advantages encourage the free movement of energy components across areas, and reduce the geographical agglomeration of energy price distortions, on the other hand, should decrease market segmentation.

Energy price changes must be pushed simultaneously as new technologies develop and energy usage is optimized. Hence, the government launched the Egyptian Pollution Abatement Project (EPAP), which seeks to encourage renewables production (Hamed and El Mahgary, 2004). The issue of pollution is a primary concern for China due to China's importation of oil and gas to meet rising domestic consumption. As a result, the government has adopted measures to meet this increasing demand, neglecting energy efficiency. The growth in fossil fuel supply has worsened the pollution rate. The country bore the brunt of the most damage cost of air pollutions, which is 21% of its GDP in the region, responsible for the overall 44% environmental costs. Given this background, renewables are seen as cleaner energy sources to help achieve energy security and avoid pollution.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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The International Spillover Effect of Import Trade on Energy Efficiency in the Post-COVID-19 Era: Evidence From China

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China is in a transition period—its government has been expanding imports and pushing itself to shift from a world factory to a world market. One of the aims is to promote energy reform and ensure energy security. Taking the resource-based regions of China as objects, based on 2003–2017 panel data, this paper investigates energy efficiency loss by the stochastic frontier approach and the effects of different technical inefficiency items. Surprisingly, quantitative results show that 99.9% energy efficiency loss in these regions is caused by technical inefficiency (which had never been found and discussed in previous studies). However, this does not mean that China's efforts to expand imports as a way to improve energy efficiency and energy security are undesirable. Instead, interestingly, it is import (–0.083***) rather than industrial structure (0.524***) that can significantly reduce energy efficiency loss. Then, it employs the counter-fact test to quantify the positive accelerating effect of human capital (average as high as 4.1%) as a key factor of absorptive capacity in the technology spillover. Lastly, it puts forward the corresponding policy suggestions in energy fields, to solve the problem effectively, especially the "comprehensive technology spreading center" and "innovative three-dimensional talent supplementary and flow mechanism."

Keywords: expanding import, energy efficiency loss, technology spillover, human capital, accelerating effect

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INTRODUCTION

China is in a transition period of high-quality economic development—its government has been expanding imports since 2012 and pushing itself to shift from a world factory to a world market. One of its aims is to promote energy reform and ensure energy security through the expansion of import trade, particularly the trade in the energy field (Rauf et al., 2021). Expanding imports will be conducive to fostering new growth areas in energy consuming and accelerating the improvement of the country's energy efficiency (Yang et al., 2021).

How to improve energy efficiency effectively through import is a long-term strategic task to ensure energy security (Nadeem et al., 2020; Akram, et al., 2021; Khan et al., 2021b; Tanveer et al., 2021). In the past 10 years, China has become the world's largest energy consumer and importer due to China's economic development (Hao and Wu, 2021; Ren et al., 2021), especially the needs of industrial development. According to the International Energy Agency, China's energy consumption, including coal, oil, natural gas, nuclear power, and hydropower, reached 2.252 billion tons of oil equivalent in 2009, overtaking the United States as the world's largest energy

consumer. In 2017, China's oil imports reach 420 million tons, surpassing United States as the world's largest oil importer. In 2018, China has overtaken Japan as the world's largest importer of natural gas with 120 billion cubic meters of natural gas imports. However, with the sharp increase in imports in the energy field, the energy efficiency in China's resource-based regions has no obvious improvement, which causes reflection on the role that imports can play in such a transition period. Is it feasible and practical to promote energy reform and ensure energy security through the expansion of import trade? Since 2020, the COVID-19 epidemic broke out and spread rapidly around the world, which brought great impact to the production and life of all countries. China's energy sector is also undergoing profound transformation due to this epidemic crisis. Under this background, it is more meaningful to discuss the influence of import trade on energy efficiency.

Along with the accelerating process of economic integration, the impact of international trade on energy efficiency in developing countries is becoming a new concern of scholars (Ahmad et al., 2021a), which is not only related to the speed and quality of their current economic development but also determines its sustainability in the future. The effect of international trade on energy efficiency is the improvement caused by international technology spillover. The four main channels of international technology spillover are FDI (foreign direct investment), OFDI (outward foreign direct investment), and import and export trade.

The existing researches on the improvement of energy efficiency by international technology spillover have relatively adequate dimensions: the increase of enterprise research and development (R&D) expenditure (Shiell and Lyssenko, 2014; Wang and Feng, 2018; Saudi et al., 2019; Khan et al., 2021a), the improvement of enterprise absorptive capacity (Wang et al., 2018; Bu et al., 2019), the adjustment of domestic industrial structure (Del Bo, 2013; Doytch and Narayan, 2016; Gui et al., 2017; Lei et al., 2017; Haug and Ucal, 2019), individual willingness (Irfan et al., 2021a; Irfan et al., 2021b; Irfan et al., 2021c), the increase of imitation capacity in competitor enterprise (Baltabaev, 2014; Merlevede et al., 2014; Wang et al., 2014), and green technology innovation (Ali et al., 2021; Nuvvula et al., 2022). Representative views are the demonstration effect of more advanced technologies caused by FDI and the reverse technology spillover of OFDI reflected in optimizing the allocation of resource (Chen et al., 2016; Wu et al., 2020b), the effect of export trade reflected in the export process on promoting R&D in order to achieve international quality standards (Oskarsson and Yetiv, 2013; Xin and Liu, 2013; Geng and Yao, 2015; Irfan et al., 2020a), the effect of import trade reflected in advanced product applications, and R&D promotion due to market competition (Teng, 2012; Ohlan, 2015; Peng and Cao, 2015).

Regarding international trade and energy efficiency, researches have two strands. The first strand is comprehensive analysis. From the perspective of factor substitution, energy is a complement to raw materials and capital and a substitute for labor (Welsch and Ochsen, 2005; Ahmed et al., 2021b; Dagar et al., 2021) to further promote efficiency in the energy sector. From the perspective of technological changes and rising energy prices, it contributes to the improvement of energy efficiency in China (Crompton and Wu 2005) and electricity consumption (Ai et al., 2020; Abbasi et al., 2021a; Jan et al., 2021). From the perspective of the potential importance of endogenous technical change and international technology spillovers, international trade enables developing countries to have access to advanced technology and equipment in developed countries, to reduce the intensity of energy consumption (Elavarasan et al., 2021a; Elavarasan et al., 2021b; Gerlagh and Kuik 2014; Iqbal et al., 2021; Mani et al., 2021; Razzaq et al., 2021; Razzaq et al., 2021). From the perspective of accelerated market-oriented reform and openness, trade openness is an important factor leading to the continuous improvement of China's energy efficiency (Fan et al., 2007). From the perspective of trade type, researchers extended the analyses and investigated the overall rebound of local energy efficiency improvements (Koesler et al., 2016) and spillover effects of oil imports (Bigerna et al., 2021). Other findings indicate that with trade liberalization, energy use increases and carbon emissions rise, and developing nations will risk energy efficiency decline (Lee and Zhang 2009; Irfan et al., 2020b; Ahmad F. et al., 2021).

The second strand is comparative analysis (between import and export). From the perspective of trade products, by analyzing the input–output tables, some researchers found that the import of some energy-intensive products is one of the reasons for the decrease of energy consumption intensity in China in 1978–1995 (Garbaccio et al., 1999). Kahrl and Roland-Holst further explained that China's energy efficiency fluctuations were due to an increase in exports of high energy-consuming products (Kahrl and Roland-Holst 2008). Using the input–output analysis, other researchers analyzed the embodied CO_2 emissions of China's import and export products and suggested that China should carry out electricity pricing reforms and increase renewable energy to improve its energy efficiency (Lin and Sun 2010). From the perspective of the trade scale, the import and export trade scale is an important factor in the optimization of industrial structure, and the latter is conducive to improving energy efficiency (Chang and Hu 2010). Besides, by constructing an environmental efficiency index for 111 countries, researchers empirically proved that environmental efficiency including energy efficiency was strongly affected by international trade, both through increased exports and increased imports (Doganay et al., 2014). From the perspective of trade policy, it is found that oil import tariff and a steady increase in oil imports leave oil-importing countries increasingly vulnerable to future oil price shocks and change their energy efficiency (Suranovic, 1994). Compared with export trade, import trade is more closely related to imitation innovation in China because of its particular trade structure—export is characterized by low–middle technology products and raw material, while import is characterized by middle–high technology products.

In previous studies, scholars have made abundant researches, but there are some points to be perfected: 1) although scholars agree on the international technology spillover as a breakthrough in energy efficiency improvement, there is no in-depth discussion from the perspective of expanding imports to study the subject

and this topic has long been neglected, which is seriously out of touch with practice, especially in view of the rapid rise of developing countries on their dependence on imported energy; 2) existing studies generally directly discuss the effect of international trade or foreign direct investment on the overall energy consumption, ignoring the trade characteristic and regional heterogeneity, such as resource-based areas; 3) the existing research generally directly examines the impact of human capital on energy utilization, and little attention is paid to quantifying the accelerating role of human capital in the process of import trade affecting energy efficiency, which leads to no clear direction for energy policymaking in solving these problems.

The situation China faces is very typical, in the following three aspects: 1) as a developing economy, in accelerated development period, the dependence of its economic development on energy imports is increasing at a fast speed, and this trend is gradually emerging in some developing countries as a characteristic; 2) the Chinese government strongly advocates imitation innovation in energy reform, advocates the energy sector to give full play to the technology spillover role of import trade to promote energy efficiency and achieve technological catch-up, which is a feasible way that developing countries will most likely adopt in the future; 3) in practice, the effect of import has not yet been effectively played, and how to optimize the existing path is of great reference to other developing countries.

Compared with other regions, in resource-based regions, the energy efficiency improvement caused by import trade is a more typical reflection of the technological spillover effect of import trade. About 85% of coal, 23.2% of oil, and 70.1% of natural gas of China are concentrated in its western regions, known as resource-based regions. Economic growth in these regions is highly dependent on energy supply. In 2013, China put forward the concept of the "Silk Road Economic Belt." It is of great practical significance to improve energy efficiency in these regions through import trade against the background of economic opening. At the same time, the backward economic situation in these regions has also constrained the improvement of the level of education and human capital. So, can import trade effectively improve the energy efficiency in these regions? What are the key agent factor and specific policy adjustment direction in this process? Is there heterogeneity? Answering these questions is of great practical value not only for China but also for the resource-based areas of other developing countries as beneficial references.

The main contribution of this paper is the following. First, we take the resource-based regions of China as objects to investigate energy efficiency loss by the stochastic frontier approach and the effects of different technical inefficiency items, particularly the import trade. This study extends the current body of knowledge regarding technical inefficiency items and energy efficiency loss in resource-based regions in developing countries. Second, this paper analyzes the underlying causes of the heterogenous effect, especially the reasons why it is import rather than industrial structure that can significantly reduce energy efficiency loss. Third, this paper quantifies the accelerating effect of human capital as a key factor of absorptive capacity in the technology spillover. Besides, this paper contributes to the research on energy efficiency by putting forward corresponding policymaking suggestions. This provides new insight into reducing energy efficiency loss *via* import trade in China and other developing countries.

The remainder of this study is organized as follows. The section *Model Construction and Data Source* includes our basic model construction, a description of the variables, and data sources. The section *Empirical Results and Analysis* provides a detailed description and analysis of the empirical results. The section *Counterfactual Test of Energy Efficiency Improvements* presents further discussion on the repair effect of human capital in the energy efficiency gap and analyses of the underlying causes. The last section concludes and discusses policy implications.

MODEL CONSTRUCTION AND DATA SOURCE

Model Construction

According to the existing research (Kashani 2005; Hu 2014; Ouyang and Sun 2015; Fetanat and Shafipour 2017; Wu et al., 2020a; Hao et al., 2021; Wu et al., 2021), this paper uses the stochastic frontier model to calculate the energy efficiency in resource-based regions in China. Its general expression is in the following form:

$$Y_{\mathrm{it}} = f(x_{\mathrm{it}}, t)\exp(v_{\mathrm{it}} - u_{\mathrm{it}}) \tag{1}$$

Y_{it} is the total economic output of the year t for the region i, and x_{it} is the input element for the year t of the region i; $f(\cdot)$ is a frontier output on the production boundary. $v_{it} - u_{it}$ is a composite error, v_{it} is a random disturbance, independent of u_{it}, and $v_{it} \sim \mathrm{N}(0,\sigma_v^2)$; u_{it} represents individual impact, technical inefficiency, and $u_{it} \sim \mathrm{N}^+(u,\sigma_v^2)$. If $u_{it} = 0$, indicates that the technology is effective, the decision unit is at the frontier of production. Otherwise, the decision unit is located below the frontier of production.

Because trans log production function allows more substitution and conversion modes and it is also more flexible in the actual utilization process, this paper selects it as stochastic frontier production function $f(\cdot)$. After processing, the final expression is

$$\begin{aligned}\ln Y_{\mathrm{it}} = {} & \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \beta_3 \ln E_{it} + \beta_4 \ln L_{it} \ln K_{it} \\ & + \beta_5 \ln L_{it} \ln E_{it} + \beta_6 lnE_{it} \ln K_{it} + \beta_7 \ln L_{it}^2 + \beta_8 \ln K_{it}^2 \\ & + \beta_9 \ln E_{it}^2 + v_{it} - u_{it}\end{aligned} \tag{2}$$

β_0 is a constant, and $\beta_1, \ldots, \beta_9$ represent the regression coefficients of labor input, capital input, energy input, and quadratic term in production activities, respectively. Furthermore, technical inefficiency items can be calculated:

$$u_{\mathrm{it}} = \alpha_0 + \alpha_k Z_{it} + \mu_{it} \tag{3}$$

α_0 is a constant, and Z_{it} indicates factors affecting the technology inefficiency. α_k is the parameter to be evaluated, reflecting the

TABLE 1 | Definitions and sources of each technical inefficiency item.

Variable name	Sources	Interpretation of indicators
indus	He et al. (2013)	Industrial structure
ep	Li et al. (2018)	Energy prices
ecs	Ahmad et al. (2016)	Energy consumption structure
import	Lau. et al. (2014)	Import trade
humc	Shao and Yang (2014)	Human capital

impact of various factors on energy efficiency in each region. $\alpha_k > 0$ indicates that this factor has a positive effect on energy efficiency loss, that is, the factor has a negative impact on energy efficiency, and $\alpha_k < 0$ indicates that the factor has a positive effect on energy efficiency. μ_{it} is a random error.

Data Source and Variable Description

Data Source

The panel data for the empirical analysis of this paper were mainly taken from the *China Statistical Yearbook*, the *China Statistical Yearbook on Science and Technology*, and the *China Energy Statistical Yearbook*. Some of the data came from regional statistical bulletins from 2004 to 2018.

Variable Description

1) Explained variable: energy efficiency (*EE*). In this paper, the energy efficiency is estimated by using the stochastic frontier model, and energy efficiency (EE) can be expressed as the ratio of real output expectation to production frontier expectation:

$$EE_{it} = \frac{E\left[f\left(L_{it}, K_{it}, E_{it}\right)\middle| exp\left(v_{it} - u_{it}\right)\right]}{E\left[f\left(L_{it}, K_{it}, E_{it}\right) exp\left(v_{it} - u_{it}\right)\middle| u_{it} = 0\right]} \tag{4}$$

If $u_{it} = 0$, $EE = 1$ indicates that the production activities of the decision-making unit are at the frontier and effective. If $u_{it} > 0$, $EE < 1$ indicates that the decision unit production activities are below the frontier and ineffective; there is a certain loss of efficiency. L, K, and E represent the input elements of the labor force, capital, and total energy consumption, respectively. This paper uses the number of employees in these regions over the years as a labor input (Ouyang et al., 2018), fixed asset investment processed by the perpetual inventory method in these regions over the years as capital input (Hu, 2012), and total energy consumption (million tons of standard coal) as the energy input (Sharma. Et al., 2002). It can be seen that *EE,* output *Y*, labor input *L*, capital input *K*, energy input *E*, and technical inefficiency items are closely related.

2) Explanatory variables: technical inefficiency items. The technical inefficiency items of this paper mainly include industrial structure, energy price, energy consumption structure, import trade, and human capital, among which import trade and human capital are the core independent variables.

Import trade (*import*): Import trade is the main international technology spillover channel. Therefore, this paper employs the import trade volume of each region during the investigation period to denote the import in trade transition (Lau. et al., 2014). The first step is converting the unit of total import into RMB according to the average exchange rate of RMB against the US dollar that year.

TABLE 2 | Estimated results of main effects of variables.

Main effect			
Distance function		**Inefficiency function**	
lnL	1.821***	*indus*	0.524***
	(3.75)		(2.97)
lnK	0.946*	*ep*	−0.006
	(1.86)		(−1.59)
lnE	−2.064**	*es*	−0.235
	(-2.04)		(−1.52)
$[lnL]^2$	−0.078*	*import*	−0.083***
	(−1.71)		(−6.15)
$[lnK]^2$	−0.110**		
	(−2.16)		
$[lnE]^2$	0.080		
	(0.39)		
lnL lnK*	0.001		
	(0.02)		
lnL lnE*	−0.028		
	(−0.18)		
lnK lnE*	0.128		
	(0.64)		
σ^2	0.031***		
	(8.63)		
γ	0.999***		
	(114.67)		
The log value	80.501		
Unilateral LR test value	29.486		

*Note: *** is at 1 percent of significance; **is at 5 percent of significance; *is at 10 percent of significance.* t *statistic in parentheses.*

Industrial structure (*indus*): Generally speaking, the secondary industry is dominated by the manufacturing industry, while the tertiary industry is mostly service industry, and the energy consumption of secondary industries is higher than that of tertiary industries, which means that with the continuous upgrading of industrial structures, the energy efficiency in regional production activities will be improved. So, in this paper, regional industrial structure is one of inefficiency items, the advanced degree of industrial structure in various regions can be calculated as follows (He. et al., 2013):

$$indus_{it} = \sum_{m=1}^{3} y_m * m = y_1 * 1 + y_2 * 2 + y_3 * 3 \tag{5}$$

Energy prices (*ep*): Energy prices can affect the cost of energy use. When prices rise, the cost of energy use increases, which will encourage producers to raise an awareness of energy conservation and reduce energy waste, thereby improving energy efficiency (Li, 2018). In this paper, fuel and the power purchase index denote energy prices.

Energy consumption structure (*ecs*): The structure of energy consumption will have an important impact on energy efficiency. When lower-utilization energy sources such as coal account for a higher proportion of energy consumption, energy efficiency will

TABLE 3 | Estimated results of regulating effect of human capital.

Regulating effect			
Distance function		**Inefficiency function**	
lnL	1.736***	*indus*	0.618***
	(4.66)		(4.64)
lnK	4.386***	*ep*	−0.006***
	(8.33)		(−3.73)
lnE	−7.100***	*es*	−0.088
	(−8.50)		(−1.28)
$[lnL]^2$	−0.049	*import*	−0.256***
	(−1.21)		(2.83)
$[lnK]^2$	−0.001	*humc*	−0.055
	(−0.01)		(−1.32)
$[lnE]^2$	0.921***	*import*humc*	−0.032***
	(5.73)		(−3.03)
lnL lnK*	0.259***		
	(3.68)		
lnL lnE*	−0.314***		
	(−2.26)		
lnK lnE*	−0.708***		
	(−4.42)		
σ^2	0.020***		
	(5.04)		
γ	0.948***		
	(32.30)		
The log value	88.068		
Unilateral LR test value	44.62		

be reduced, and conversely, energy efficiency will be higher. In this paper, the proportion of coal consumption in total energy consumption in the region denotes the energy consumption structure (Ahmad et al., 2016).

Human capital (*hum*): One of this paper's focuses is the repair impact of human capital on energy efficiency loss as the key factor that hinders the international technology spillover. Therefore, from the perspective of technology absorptive capacity, this paper chooses the average number of years of schooling in these resource-based regions as the agent variable of the human capital level (Shao and Yang, 2014). The definitions and sources of the technical inefficiency variables are shown in **Table 1**.

EMPIRICAL RESULTS AND ANALYSIS

Analysis of Basic Model Estimation Results

Based on the above research methods and variable design, this paper estimates the energy efficiency and its influence factors.

It first examines the technology spillover impact of import trade on energy efficiency, and the estimated results of the main effect are shown in **Table 2**.

From the estimated results in **Table 2**, in the main effect, σ^2 and γ pass the test of significance, and $\gamma = 0.999$ indicates that 99.9% of energy efficiency loss is caused by technology inefficiency. The coefficient of import is −0.083, passing the test of significance, suggesting that imports can reduce energy efficiency loss obviously through the international technology spillover. Technology transfer and technology imitation brought by the import trade can exert such a positive effect closely related to China's import trade characteristic. In the import process, the advanced technology included in products will overflow to resource-based regions, as well as some advanced management experience and knowledge skills, enhancing the technology level in these regions directly and indirectly. These technologies not only include production technology but also the energy saving, energy utilization in the use of products. In addition, the improvement of the technological level can also optimize the proportion of existing energy factors to improve energy efficiency. In these resource-based regions, associated local enterprises will be able to learn and imitate the intermediate product in the using process, then develop similar production technology through imitation. Interestingly, it is the import trade rather than industrial structure in resource-based regions in China that has a significant positive effect on energy efficiency, which is contrary to others' research (Zhou et al., 2013; Wen et al., 2015). The main reason is that the vulnerable industrial structure in these regions has a heavy dependence on low-rank energy. However, the import trade would bring technology spillover through advanced products and energy-saving equipment.

After identifying import as the main driving factor, in order to investigate its improvement potential, this paper furthermore examines the regulating effect of human capital. According to previous studies, human capital is the key influencing factor in technology spillover absorption capacity. The estimated results are shown in **Table 3**.

According to the regulatory effect model, γ passing the test of significance, $\gamma = 0.948$ means that 94.8% of the energy efficiency loss is caused by technology inefficiency items. The coefficient of *import*humc* is -0.032 and passes the significance test, showing that the improvement of human capital can positively accelerate the energy efficiency improvement caused by the spillover of import trade. In fact, consistent with many researches, the technology absorption capacity from local enterprises and practitioners is the key influence factor in the process of absorbing and imitating advanced technology and management knowledge. If processing technology, management experience, and product technology overflowed by imports to the resource-based regions cannot be absorbed by local enterprises, imports cannot effectively realize energy conservation and emission reduction in the local enterprise production activities. Besides, resource-based regions have unique human capital structure: the average human capital level is much lower than other regions, and talents' stock is obviously unbalanced in these resource-based regions.

The coefficient of *humc* is −0.055 and does not pass the significance test showing that as an important technology spillover absorptive factor, human capital can bring a slight reduction to energy efficiency loss. The main reason is that in resource-based regions, the overall human capital quality is relatively low. Although some regions' human capital is at a high level, for example, Chongqing and Shaanxi, other regions are still at a low level. So when observing solely, its effects are limited.

Interestingly, the industrial structure in resource-based regions in China has a significant negative effect on energy

efficiency, indicating that the regional industrial structure upgrade did not improve the energy efficiency in these resource-based regions. This conclusion is inconsistent with previous studies focusing on the national level in China and developed nations (Wen et al., 2015; Yu et al., 2015; Lv et al., 2017; Abbasi et al., 2021b). This inconsistency is due to the low-level industrial structure in the transition period from the primary industry to the secondary industry. In these regions, industrial structure upgrade is mainly based on the development of the secondary industry with a high energy consumption of coal and oil. So, the empirical result is interesting: an industrial structure upgrade in resource-based regions in China will cause energy efficiency loss; the coefficient of *ep* and *es* are significantly negative, showing that the increase in the energy price and energy consumption structure optimization can improve the energy efficiency in these regions. As stated earlier, the increase of energy prices will affect the cost of energy use and enhance the energy-saving consciousness of producers to reduce the energy waste. When the energy consumption structure upgrades, a proportion of coal and oil reduces in energy consumption; then, indirectly, energy efficiency will be improved.

COUNTERFACTUAL TEST OF ENERGY EFFICIENCY IMPROVEMENTS

According to the above, it can be seen that the improvement of human capital can significantly strengthen the positive effect of import trade on the energy efficiency in these regions. Besides, resource-based regions have unique human capital structure. Therefore, it is necessary to thoroughly explore its positive accelerating effect and regional heterogeneity.

Regarding human capital and energy efficiency, researches' focus is from the perspective of absorption capacity to study the impact of international technology spillover on energy efficiency. The level of human capital and internal composition not only affect the absorptive capacity of technology but also restrict local original innovation capacity, both of which influence the improvement of energy efficiency. Technology spillover situations are different in developed and developing countries, related to the human capital threshold. Besides, reasonable human capital structure is also important to the innovation ability of a country (Nelson and Phelps 1966; Lan et al., 2012; Lan and Munro 2013).

However, the quantitative regulating effect of human capital in resource-based regions has been neglected. This paper would like to make a quantitative investigation on this improvement and calculate the repair effect of human capital on the energy efficiency gap. According to the relevant research (Salmi, 2008), setting the inefficiency function in stochastic frontier analysis, the counterfactual test method is used to quantify the energy efficiency improvement. The counterfactual test method could reveal efficiency change process (Lin and Du, 2013; Bai and Bian, 2016). First, make the following settings for **Eq. 3**:

$$u_{it} = \alpha_0 + \alpha_1 indus_{\mathrm{it}} + \alpha_2 ep_{it} + \alpha_3 es_{it} + \alpha_4 import_{it} + \mu_{it} \tag{6}$$

Then, plug the **Eq. 6** just derived from **Eq. 3** into **Eq. 4**, the energy efficiency EE_1 is calculated at this time. Further, this paper takes into account the regulating effect of the human capital and makes the following assumptions about the inefficiency function:

$$u_{it} = \alpha_0 + \alpha_1 indus_{\mathrm{it}} + \alpha_2 ep_{it} + \alpha_3 es_{\mathrm{it}} + \alpha_4 import_{it} + \alpha_5 hum_{it} + \alpha_6 import^{*} hum_{it} + \mu_{it} \tag{7}$$

Plug **Eq. 7** into **Eq. 4**; the energy efficiency EE_2 is calculated. The regulating effect of human capital on energy efficiency can be quantified as

$$\Delta EE = EE_2 - EE_1 \tag{8}$$

According to **Eq. 8**, this paper quantifies the regulating effect of human capital on energy efficiency in various regions under the condition of import trade. The results are shown in **Table 4**.

As can be seen from **Table 4**, with the exception of individual negative data, on the whole, during the investigation period, human capital can obviously improve the energy efficiency value under the condition of import trade. Interestingly, three results should be noted: 1) the energy efficiency in each region or the whole (4.1%) has been improved apparently over the years; 2) from the mean, the energy efficiency improvement values of Qinghai, Ningxia, and Xinjiang are 6.9, 10.4, and 8.5% respectively, which are significantly higher than other regions; 3) in some resource-based regions with relatively high human capital, typically Sichuan (1.3%) and Shaanxi (1%), the human capital advantage has no significant effect on energy efficiency improvement caused by increasing imports.

Obviously, in the northwest regions, the effect of the positive accelerating effect of human capital on energy efficiency improvement brought by import overflow will be significantly greater than that in the southwest regions. There are two main reasons. First, compared with the southwest regions, in the northwest regions, the "marginal" promotion effect of import trade on the technology level and energy efficiency is more significant due to their original low economic development level and openness, a relatively backward technical level. Second, in the northwest, the education level and talent policy are not as good as the southwest, so the absorptive ability of technology is weak, and the technology transfer and technology imitation effect brought by import trade cannot be fully exerted. However, it will indirectly encourage energy-saving technologies and the use of new energy in the northwest regions. Therefore, the improvement effect of human capital on the energy efficiency in the northwest is higher than the overall mean value, whereas in the southwest, it is lower than the overall mean value.

In order to investigate the spatio-temporal changes of the energy efficiency improvement in various regions, this paper depicts a line chart of the energy efficiency improvement values in various regions, as shown in **Figure 1**.

As can be seen from **Figure 1**, there are also obvious regional differences in the positive regulating effect of human capital on the energy efficiency improvement caused by import trade. Its quantitative results can be divided into three classes. 1) The

TABLE 4 | The regulating effect of human capital on energy efficiency.

	Guangxi	Chongqing	Sichuan	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang
2003	0.136	0.014	0.010	0.025	0.020	0.009	0.060	0.020	0.001
2004	0.088	0.003	0.017	0.008	0.012	0.017	0.045	−0.001	0.013
2005	0.071	−0.008	0.022	−0.001	0.004	0.022	0.016	0.017	0.024
2006	0.060	−0.015	0.025	0.000	0.002	0.020	0.000	0.033	0.040
2007	0.048	0.015	0.026	0.003	0.002	0.016	0.015	0.055	0.054
2008	0.040	0.025	0.024	0.008	0.005	−0.010	0.031	0.086	0.069
2009	0.028	0.030	0.015	0.009	0.008	0.004	0.036	0.079	0.076
2010	0.018	0.029	0.014	0.009	0.008	0.000	0.053	0.110	0.099
2011	0.010	0.026	0.016	0.008	0.012	0.003	0.079	0.146	0.116
2012	−0.005	0.036	0.012	0.007	0.014	0.007	0.099	0.156	0.128
2013	0.015	0.041	0.003	0.006	0.016	0.008	0.113	0.165	0.128
2014	0.027	0.048	0.003	0.002	0.015	0.006	0.120	0.165	0.139
2015	0.045	0.058	0.001	0.008	0.009	0.002	0.116	0.177	0.129
2016	0.043	0.061	0.002	0.009	0.012	0.004	0.119	0.180	0.125
2017	0.050	0.070	0.005	0.010	0.015	0.007	0.126	0.178	0.137
Mean	0.045	0.029	0.013	0.007	0.010	0.008	0.069	0.104	0.085

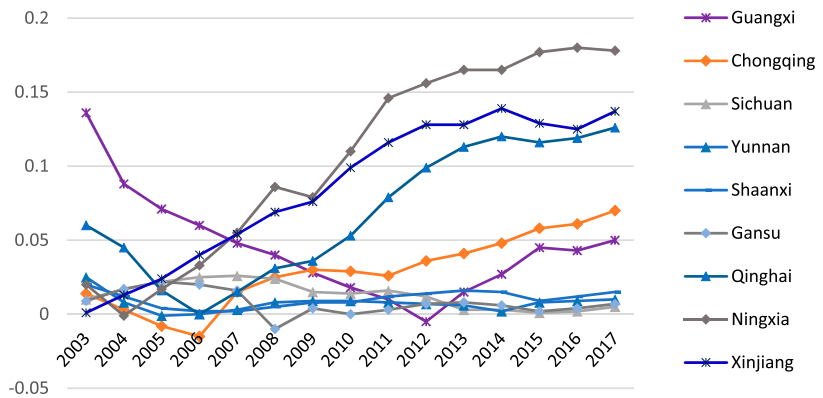

FIGURE 1 | Trend Chart of the improvement effect of regional human capital.

positive effect in Sichuan, Yunnan, Shaanxi, and Gansu provinces has been fluctuating at a low level. The positive effect of human capital on the improvement of energy efficiency in Sichuan even declines, showing a "marginal decline" characteristic. This finding is inconsistent with previous studies (Nelson and Phelps, 1966; Lan et al., 2012; Lan and Munro, 2013). The main reasons are different in these four regions: Shaanxi and Sichuan have a relatively high level of human capital, but they are facing severe brain drain; industrial structures in Yunnan and Gansu are singular without interdevelopment and systematic development, so the effect of human capital will be hindered. 2) In Guangxi, human capital has an obvious marginal-decline positive effect on the improvement of energy efficiency caused by import trade in the early stage and reached the lowest value in 2012, followed by a weak increase of positive effect, showing a "strong decline→weak increase" characteristic. The main reason is that the local government is actively promoting tourism development, the talents introduced mainly focusing on tourism. 3) In comparison, in Qinghai, Ningxia, and Xinjiang, the positive effect is increasing year by year, showing a "marginal increase" characteristic, mainly due to the relatively backward initial development conditions of these three regions. These regions have weak economic base, a relatively backward technical level, and a low level of education and human capital. Therefore, improving factor endowments would have an apparent "marginal" boost to both the absorption capacity of technology spillover and the technological innovation, which would significantly improve the energy efficiency in these regions.

CONCLUSIONS AND POLICY IMPLICATIONS

In order to investigate the influence of import trade on the energy efficiency in resource-based regions and the role of human capital in it, this paper takes the gradually open and resource-intensive regions in China as the objects, and uses the stochastic frontier analysis method to carry on the measurement analysis. Surprisingly, quantitative results show that 99.9% energy efficiency loss in resource-based regions in China is caused by technical inefficiency. However, this does not mean that China's efforts to expand imports as a way to improve energy efficiency

and ensure energy security are undesirable. Instead, interestingly, it is import rather than industrial structure that can significantly improve energy efficiency in resource-based regions. The research finds that the import trade obviously enhances the energy efficiency in these regions; the improvement of human capital can positively accelerate the effect of import trade on energy efficiency. In addition, an upgrade of the human capital structure can increase the energy efficiency improvement caused by import trade by 4.1% on the whole.

Based on the above conclusions, this paper puts forward the following policy suggestions.

Firstly, import trade can obviously promote energy efficiency through international technology spillover. Therefore, these regions should seize the opportunity of "Silk Road Economic Belt" construction, continue to expand the opening to the outside and import trade, and actively build a platform for cooperation and exchange through three measures: 1) vigorously increase the import of high-tech intermediate products and strictly control and reduce the import of intermediate products with low technological content and high energy consumption; 2) in order to improve the energy efficiency by introducing and absorbing advanced technology and management experience and fully exert the technology transfer and technology imitation effect of import trade, the local government can implement product subsidies and preferential tax to the enterprises importing energy-saving products; 3) the government should take setting up a comprehensive technology spreading center into account, which can be based in Shaanxi, a province with abundant advanced educational resources, especially universities, which can not only make full use of existing endowment but also innovatively solve the two problems—unbalanced technology spillover caused by unbalanced import trade among different regions and the lack of effective ways in the technology information exchange of imported products. Besides, for Chongqing, Sichuan, and Shaanxi, it is necessary to make use of location advantages to increase import trade and exert an innovative leading effect. For Gansu, Qinghai, Ningxia, and Xinjiang, it is feasible to encourage enterprises to import energy-saving products and undertake imitation innovation *via* subsidies and preferential tax.

Secondly, the improvement of human capital can strengthen the positive effect of import trade on energy efficiency, so these regions should promote technology absorption capacity through the following ways: 1) to improve the overall human capital structure, local governments should increase investment in education funds and focus on the development of basic education, as well as expanding the high-level human capital stock *via* actively introducing scholars and experts from the east and central regions and training professional talents; 2) to prevent the brain drain in these regions and attract and retain talents, policies should be made to promote the reform of the household registration system, lower the threshold for the settlement of talents, and improve the welfare benefits and working environment; 3) the improvement effect of factor endowment on energy efficiency in the northwest regions is obviously stronger, so while strengthening basic education and attracting talents, the northwest regions should pay special attention to reducing the phenomenon of the "excavation" of talents from the east and central regions and adopting the effective preferential policies to retain talents, for example, providing favorable treatment and establishing a sound promotion system. In addition, these regions should take setting up an innovative three-dimensional talent supplementary and flow mechanism into account—aiming to combine attracting talents as many as possible to serve for a short period and exerting talent advantage sustainably together—the first dimension is to establish an imitation innovation R&D center about introducing technology and imported products in Shaanxi and Sichuan (rich in higher education resources) to provide re-innovation technology products and train professional and technical personnel for energy enterprises every year; the second dimension is to carry out a "talent flow assistance" plan, just like the existing "partner assistance" plan in Xinjiang, to send a professional R&D team and graduate interns in the energy field, from universities to key enterprises in batches; the third dimension is to promote a large-scale application of re-innovative technology based on imported products and motivate the junior technical personnel to innovate with awards in the form of innovation performance (Abbasi et al., 2021c; Fisher-Vanden et al., 2006; Mielnik and Goldemberg, 2002; Weng et al., 2018).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available from the authors on reasonable request.

AUTHOR CONTRIBUTIONS

XH: Conceptualization, Project administration, Formal analysis, Writing—review and amp, Editing. XW: Data curation, Writing—original draft. YX: Software, Visualization, Writing original draft, Writing—review and amp, Editing, Formal analysis.

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Energy Efficiency in the Post-COVID-19 Era: Exploring the Determinants of Energy-Saving Intentions and Behaviors

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The COVID-19 pandemic has a long-lasting influence on global economies. Households are expected to consume more electricity for their usual routine activities due to mandatory stay-at-home restrictions, resulting in greater energy utilization. The proposed study seeks to investigate the most relevant energy consumption factors amid the COVID-19 pandemic. The study employs a structural equation modeling approach to evaluate the responses from 511 Pakistani residents. Empirical results report a positive and significant association among perceived behavioral control (PBC), perceived environmental concern (PEC), perceived monitory benefits (PMB), and intention to save energy (ISE). Positive anticipated emotions (PAE) is found to be a significant predictor of ISE and energy-saving behavior (ESB). As a step further, we extend the analysis to find the moderating effect of perceived COVID-19 disruptiveness (PCD) between the relationship of ISE and ESB. Results reveal that PCD positively moderates this relationship. Based on research findings, policy implications and future research directions are provided for practitioners, researchers, and academicians to fulfill the country's energy needs on its way to a future of sustainable development.

Keywords: perceived behavioral control, perceived environmental concern, perceived monetary benefit, intention to save energy, energy saving behavior, perceived COVID-19 disruptiveness

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INTRODUCTION

The worldwide COVID-19 pandemic has afflicted the majority of countries and has influenced the activities of every household. Many industries, including energy, transportation, manufacturing, and residential construction, have been severely damaged by the pandemic (Qarnain et al., 2021). Severe lockdowns by local governments have compelled household inhabitants to utilize more energy for their routine tasks, resulting in higher energy consumption. For this research, energy usage has been investigated in Pakistan during the COVID-19 pandemic. More than 200 M Pakistanis were limited to their homes during the country-wide lockdown, resulting in dramatically higher residential energy consumption (Baloch et al., 2021). The largest Pakistani cities, such as Lahore and Karachi, reported a substantial increase in residential energy usage during this period. This growth in household energy

consumption may revoke the comparable decrease in industrial and commercial energy consumption (Irfan et al., 2021a; Zhang et al., 2021).

Presently, research activities focusing on household energy consumption behavior may be classified into three broad categories, including (i) economic, (ii) technological, and (iii) psychological behavior-oriented perspectives (Arawomo, 2017; da Silva and Cerqueira, 2017; Zhou and Yang, 2016). However, several investigations have indicated that the impacts of these procedures are relatively scarce in reality (Wang et al., 2018a). This is due to the fact that, in comparison to other household expenses, energy expenditure is very small and typically displays low price volatility (Yu and Guo, 2016). Most households are unconcerned about changes in energy prices and are reluctant to forgo their luxurious lifestyle and prosperity in their everyday lives to preserve energy (Yu and Guo, 2016). Profit-making programs seek to compensate individuals for their sacrifices by providing subsidies. Previous research has found that profit-making strategies can only be successful for a limited amount of time unless they are long-term (Handgraaf et al., 2013; Frederiks et al., 2015; Akbar et al., 2020). As a result, profit-making solutions may not successfully drive energy-saving behavior (ESB) in the long run.

Given the constraints of the industrial and technological perspectives, experts have increasingly acknowledged that the psychological behavior-oriented approach is essential in attaining energy savings objectives (Martinsson et al., 2011; Hori et al., 2013). Researchers have previously given consideration to cognitive attributes. In this regard, numerous cognitive behavior models have been produced to comprehend residential energy adoption behavior and discover the relevant influencing factors (Judith and Linda, 2009). The theory of planned behavior (TPB) is the most extensively utilized theory among other models and theories to understand consumers' energy adoption behavior (Rivis et al., 2009). In this vein, we attempt to use TPB to explain ESB from a cognitive standpoint. In contrast to the theory of reasoned action and norm activation model, TPB considers unforced factors, i.e., perceived behavioral control (PBC). As a result, it is relevant to adopt TPB as the dominant conjectural foundation for this study in order to better recognize domestic ESB.

Furthermore, numerous researchers have noticed that other cognitive attributes and variables may contribute to TPB to strengthen the model's effectiveness (Kaiser and Scheuthle, 2003; Shi et al., 2017). This study introduced an emotional factor named Positive anticipated emotions (PAE) into the TPB model to better explain ESB. The study answers the following questions: (i) to determine if these proposed factors and variables have a substantial impact on household ESB, (ii) what actions could be implemented to enhance household ESB?

The next section discusses the "Theoretical background and research hypotheses," which describes TPB as a theoretical foundation, as well as a detailed literature review and conceptual model. The section "Research methods" discusses the research design. The section "Data analysis and results" describes the testing of hypotheses. The section "Discussion" explains the findings, implications, and conclusion of the study.

THEORETICAL BACKGROUND AND RESEARCH HYPOTHESES

Theory of Planned Behavior

TPB has been extensively used in recent studies to explain how people develop behavioral intentions (Han et al., 2016; Ye et al., 2017). According to Google Scholar, this theory has been discussed about 90,000 times as of 2019. An underlying feature of a specific behavior is the intention to perform or act (Ajzen, 1985; Ajzen, 1991). It is also widely used in the realm of environmental behaviour, such as saving energy, low-carbon commuting, environmental innovation, and green buying. Three main components affect persons' behavioral intentions (Ahmad et al., 2020), namely behavioral beliefs, normative beliefs, and PBC. Scholars have widely employed TPB to measure individuals' pro-environmental behaviors, and many studies agree that TPB predicts various behavior effectively. For example, this theory has been used in past research to analyze customers' green behavioral intentions (Mancha and Yoder, 2015; Wang et al., 2018b). Furthermore, another research employed the TPB model to demonstrate that subjective norms, environmental attitudes, information publicity, lifestyles, and PBC could substantially influence residents' energy-saving behavior (Wang et al., 2014). Also, Wang et al. (2018a) investigated the influence of non-cognitive and emotional variables on residents' ESB by employing a proper framework that included the TPB and social behavior. Furthermore, a recent study used the theory of planned behavior to examine how favorable and unfavorable thoughts influence people's ISE (Fu et al., 2021). It also confirmed the moderating influence of pricing and incentive-making strategic concept on people's ISE and ESB.

Perceived Behavioral Control

The perceived ease or difficulty of performing a certain activity is referred to as PBC (Fornara et al., 2016; Sembada and Koay, 2021). Individuals are inclined to achieve a behavior when it is not difficult to do so as a choice. The worldwide outbreak of COVID-19 has influenced the majority of countries and has influenced every family's lifestyle. Legally required stay-at-home policies have compelled housing residents to consume more energy for their regular everyday operations, resulting in greater energy consumption (Qarnain et al., 2020). The growing energy consumption by housing inhabitants results in overpriced energy bills and a shortage of energy supply. However, perceived behavior may be utilized to control energy consumption, and this behavior serves as an energy conservation factor in homes, reducing the excessive energy cost.

Wang et al. (2018a) demonstrated that PBC positively affects residents' understanding of energy conservation. The more strongly individuals can control their behavior, the more intention they have to save electricity and the more inclined individuals are to acquire energy-saving habits. Moreover, several researchers have found that PBC has a favorable consequence on both behavioral intentions and actual behavior, such as ESB at home and at the workplace (Wang et al., 2014; Fornara et al., 2016). Consistent with TPB, it can be argued that residents' desire

to preserve energy would expand when they believe they have a sufficient amount of control, such as the competence, timing, abilities, and resources to execute the ESB. Some factors, such as opportunity, resource, time, knowledge, and abilities, may be beyond an individual's control and thus affect their intention to engage in a specific behavior (Gao et al., 2017). During the COVID-19 pandemic, individuals who have greater control over themselves and have the necessary knowledge and skills to conserve energy in the workplace are more likely to build the intention to save energy. Thus, we suggest the following hypothesis.

H_1: PBC is positively related to individuals' ISE

Perceived environmental Concern

The concept of PEC refers to people's views of the eco-friendly environment by adopting energy-saving behavior, emphasizing the achievements made by energy conservation behavior to the environment (He et al., 2018; Li et al., 2019). It is generally presumed that ESB is beneficial for both decreasing exhaustion of energy and preventing environmental breakdown, especially during the period of COVID-19 outbreak. Individuals acquire satisfaction from their actions as an intrinsic benefit (Kankanhalli et al., 2005; Wasko and Faraj, 2005). An individual who enjoys a specific behavior might acquire satisfaction from that behavior, which significantly encourages their positive attitude toward that behavior. Similarly, Individuals who believe they have a high degree of satisfaction from energy conservation are more inclined to acquire a favorable attitude toward the behavior

Many investigations on ESB have demonstrated the importance of environmental factors in influencing inhabitants' behavior. Steinhorst et al. (2015) investigated whether conserving energy is driven by financial or environmental benefits; the findings demonstrated that environmental discourse had a strong favorable influence on ISE. Energy consumption may be reduced through conserving energy, which eliminates carbon emissions and, as a result, helps to avoid global warming and environmental damage. This approach can be considered as an environmental benefit of energy savings (Banfi et al., 2008). Whereas the influence of ESB on the factors of environmental regulation, and based on home residents' environmental awareness and understanding, the PEC assistances variable was developed to investigate this influence on inhabitants' motivation to save energy. As a result, the following hypotheses have been proposed as:

H_2: PEC is positively related to individuals' ISE

Perceived Monitory Benefits

According to Orbell et al. (1996), the concept of perceived benefit is the anticipated opportunity that a favorable outcome would occur as a result of the suggested action. In this study, PMB is defined as inhabitants' impression of saving money during the COVID-19 crisis via electricity-saving habits, emphasizing the environmental benefits of these habits (He et al., 2018). This is an example of an intellectual sentiment that impacts a person's morality (Tsujikawa et al., 2016). He et al. (2018) investigated the process of perceived financial incentives on customers' purchasing behavior for electric vehicles in China. Wang et al. (2019) analyzed attitudes on and adoption of fossil fuels based on perceived advantage; the findings revealed that perceived advantage had a beneficial influence on the public's perspective and acceptability of green energy. Dianshu et al. (2010) investigated the relationship between electricity price and consumption level in China to explore if economic benefits have a major impact on energy-saving behavior. Several studies have been conducted to support this assumption by exploring how financial cost affects residential electricity consumption (Banfi et al., 2008; Steinhorst et al., 2015; Fu et al., 2021). Based on the description above, the study employed PMB as one of the absolute perspectives affecting home residents' intention to conserve energy and to explore how it influences household residents' energy-saving habits. Therefore, we suggest the following hypothesis.

H_3: PMB is positively related to individuals' ISE

Intention to Save Energy

Ajzen (1985) defines behavioral intention as a collection of motivating elements that impact each individual's behavior, indicating the individual's desire or effort to invest in performing the activity. Energy in overall, and electricity in particular, is a product that is required in daily life. Whether you like it or not, every household must buy and use it. ESB is the act of turning off when not needed, using high-efficiency energy, and investing in energy-saving technology to reduce energy consumption (Zaidan et al., 2021). Residential building energy consumption is not addressed during situations such as this COVID-19 pandemic (Qarnain et al., 2021). During the COVID-19 pandemic, energy consumption levels reach the maximum due to unexpected demands, resulting in high energy costs and energy waste. If the factors leading to increased consumption are identified before the pandemic demand levels, solutions may be more easily provided. According to the TPB, as a direct intervening variable of ESB, residents' ISE can substantially anticipate household ESB. In other terms, the more motivated you are to conserve energy, the more tend you are to execute it. Inhabitants' ISE is strengthened when they have a constructive orientation toward conserving energy. Residents believe they have an acceptable degree of control, such as the capability, time, skills, and opportunity to engage in the energy-saving practice. Therefore, based on the aforementioned arguments, we suggest the following hypothesis:

H_4: Individuals' ISE is positively related to ESB

Positive anticipated Emotions

Anticipated emotions are the state of mind (e.g., pleasant and unpleasant) or responses to a particular situation (Russell et al., 2017). Individuals are more inclined to participate in a situation if they have a strong expected emotion about the event or subject; unless they are hesitant to participate. In this study, PAE consists of positive psychological sensations experienced when

completing a certain behavior (e.g., home ESB). According to Han and Hyun (2018), PAE initially communicates the relevance and importance of an event or problem and then offers stimulation for executing the activity. According to interpersonal behavior theory, PAE is considered a crucial indicator in executing environmentally friendly behavior, especially during the COVID-19 crisis (Russell et al., 2017; Qarnain et al., 2021). According to Webb et al. (2013), PAE has a favorable impact on the intention to participate in ESB.

According to the above research findings, PAE is a predictor of intention to engage in eco-friendly behavior. Applying the same rationale, it can be projected that within the perspective of energy reduction, citizens are more inclined to conserve energy if they believe that conserving energy in their everyday lives is environmentally beneficial and display a PAE about conserving energy. Furthermore, we know from effective event theory that PAE is a strong determinant of genuine engagement as it stimulates a psychological desire for performance (Weiss and Beal, 2007; Han and Hyun, 2018). Following affective events theory, this study posits that PAE has a significant impact on residents' ESB. We predict that the more PAE inhabitants display, the more inclined they are to perform ESB. Given such viewpoints, we hypothesize that:

H_{5a}: PAE is positively related to individuals' ISE
H_{5b}: PAE is positively related to individuals' ESB

The Moderating Role of Perceived COVID-19 Disruptiveness

The world pandemic of COVID-19 disruption has infected most countries and has influenced the functions of every family. Compulsory stay-at-home quarantines have compelled housing residents to consume more energy for their regular everyday activities, resulting in greater energy consumption. The high energy uses by housing residents results in overpriced energy bills and a shortage of energy supply. During the COVID-19 pandemic, transportation-related air pollutants were lowered by 44.3–55.4% in Pakistan, while overall energy consumption was reduced by around 7%, increasing home energy consumption (Jiang et al., 2021). The consumption is interlinked during the COVID-19 outbreak, where a decline in energy consumption at workplaces leads to increased energy consumption at home.

Due to the changing energy use dynamics after the COVID-19 outbreak, energy consumption has extensively risen due to unanticipated demands, resulting in high energy expenditures and energy losses. According to the TPB, as a direct instrumental variable of ESB, residents' ISE can be utilized to significantly and positively predict household ESB. However, due to COVID-19 shutdowns, several research studies indicate that a spike in home-based working, freelancing, and non-work travel may alter residents' ESB due to excessive energy consumption for their regular daily operations (Webb et al., 2013; Jiang et al., 2021). As a result of the disruptive nature of the COVID-19 outbreak, the more motivated you are to conserve energy at home, the less likely you are to perform it. Residents' ISE is boosted when they have a favorable attitude toward saving energy. For example, if residents believe they do not have an appropriate level of ISE, they would be unable to perform effectively (Banfi et al., 2008). Therefore, based on the above argument, we suggest the following hypothesis. **Figure 1** represents the conceptual framework of the study.

H6: COVID-19 disruptiveness negatively moderates the influence of ISE on ESB when it is high (*vs.* low).

TABLE 1 | Sample characteristics.

Respondents profile	Frequency	Percentage %
Gender		
Male	278	73
Female	102	27
Age		
20–25	94	24.7
26–35	135	35.4
36–45	85	22.3
46–55	67	17.6
Education level		
High school or below	20	5.2
Associate degree	135	35.4
Bachelor's degree	155	40.7
Master's degree	56	14.7
PhD	15	3.9
Monthly income (PKR)		
Less than 40,000	20	5.2
41000–60000	155	40.7
61000–80000	105	27.6
81000–100000	20	5.2
100000 above	81	21.3
Family size		
1–2	115	30.2
3–4	210	55.1
More than 4	56	14.7

RESEARCH METHODS

Sample and Data Collection

The study hypotheses are investigated through survey questions collected from the citizens of Lahore between mid-March and mid-August of 2021 because Lahore has been the most seriously afflicted location since the COVID-19 outbreak in Pakistan. The Lahore city is highly populated; thereby, the impact of COVID-19 has been immense.

As a result, Qualtrics Panel Services was employed to collect internet-based survey data for this research. We distributed 700 questionnaires to resistant's (professionals and students) working from their homes owing to COVID-19 lockdown. Moreover, participants were assured that their answers would be completely anonymous. After completing the survey, 532 filled responses were returned in total. The research team verified the questionnaires, and those with missing or incomplete data

were eliminated. Overall, 511 usable questionnaires were obtained, with a 73% response rate. **Table 1** shows the demographic features of the respondents. As seen in **Table 1**, the vast majority of respondents (73.44%) are male, and 30.1% are between the ages of 26 and 35. The respondents were generally well-educated, with 70% holding a bachelor's degree. Approximately 40.7% earns a monthly income ranging from Pakistani Rupees (PKR) 41000 to 60000, and 27.6% earns a monthly income ranging from PKR 61000 to PKR 80000. The majority of the sample (55.1%) had a medium-sized family of 3–4 persons.

Measures

In this study, the constructs are all key predictors that are assessed using multiple-item scales, and they were measured using a 5-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). To measure *perceived behavior control*, we used four items scales from previous literature by Wang et al. (2018a). A sample item is "energy-saving could reduce the carbon emission". Perceived environmental concern and perceived monitory benefits were adapted from previous literature by Fu et al. (2021), and it has been measured on a seven items scale. A sample item is "I think the energy cost of my family is very high". Energy-saving intentions and behavior scale were utilized from the study of Fu et al. (2021), and the responses were assessed on a eight items scale. A sample item is "I intend to save energy in my home' and "I always set the air conditioner at the right temperature, not the lowest or highest". *Positive anticipated emotion* was also derived from Wang et al. (2018a) and assessed on a 3-item scale. A sample item is "If I take measures to save energy in my home, I will feel excited". In last, COVID-19 disruptiveness scale was adapted from Epler and Leach (2021) and consist of 4-items scales. A sample item is "My energy costs have increased as a result of COVID-19 disruption".

DATA ANALYSIS AND RESULTS

We employed the SEM approach with SmartPLS 3 and SPSS version 26 for analyzing the data. Further, to test our proposed model—a two-step approach of measurement model (MM) and structural model (SM) estimation was taken into consideration for data analysis using SmartPLS (Hair et al., 2006; Ahmad et al., 2021). Constructs' reliabilities were gauged through the MM, whereas the SM was applied to observe the relationships among the five constructs. It is known as a component-focused method and adopted to analyze the relational dimensions in the study (Urbach and Ahlemann, 2010). PLS-SEM was chosen over all other covariance-based approaches because it enables researchers to consistently analyze calculations and factor structures. Another explanation for using PLS-SEM is that it facilitates this study with a small sample size and can process the various measurement scales together (Wold, 2006; Urbach and Ahlemann, 2010). Additionally, it allows scholars to analyze the model in both reflective and formative actions. At the earlier stages of model development, the PLS method is considered vastly acceptable, which is the case in this study. Prior research indicates that a sample size of 68 is a reasonable starting point for use in PLS-SEM (Hoelz and Bataglia, 2021).

Common Method Bias

The CMB was performed using two different ways in this study to ensure whether the collected data were free from biases. First, we used one of the traditional and frequently cited methods, "Harman's one-factor test" (Harman, 1976), using SPSS. Second, we used another most commonly used PLS-SEM technique to avoid the CMB threat (Kock, 2015). According to the first approach, if a single factor accounts for >50% of the variance, it can influence the study's findings (Harman, 1976; Podsakoff et al., 2012). The second method submits that variance inflation factor (VIF) values <3.3 for the indicators can be considered the model is free of CMB (Kock, 2015). Our model results for the first approach indicate that a single factor extracts <50% of the total variance (Harman, 1976; Podsakoff et al., 2012), and according to **Table 4**, the VIF values of all items were <3.3 (Kock, 2015). In line with these results, CMB is not a serious concern in the study (Harman, 1976; Podsakoff et al., 2012; Kock, 2015).

Measurement Model Assessment

The measurement model was analyzed to confirm the reliabilities of the constructs, where the four most commonly measures were used. First, the factor loadings of all items were confirmed, where Hair et al. (2019) suggested that the loadings of items should >0.708. Thus, the items with loadings <0.708 were removed from the model. Second, Cronbach's alpha was calculated. Third, composite reliability was weighed. Fourth, an average variance extracted was estimated (Hair et al., 2019). Such measures surpass the cut-off values of 0.70 and 0.50, correspondingly (**Table 2**). Additionally, discriminant validity was also ensured via Fornell and Larcker (1981) approach (see **Table 2**). Therefore, both reliability and validity are confirmed. Furthermore, the construct's discriminant validity was also assessed using the Heterotrait-Monotrait Ratio (HTMT) method. To obtain discriminant validity using the HTMT method, HTMT values must be lower than HTMT 0.90 (Gold et al., 2015). The HTMT analysis revealed that all correlation values were smaller than HTMT 0.90, indicating that the construct is discriminant. The Heterotrait-Monotrait Ratio findings are shown in **Table 3**.

Multicollinearity

Multicollinearity was tested using VIF pre-hypothesis testing, where VIF above five is deemed problematic, suggesting a multicollinearity issue (Irfan et al., 2020a; Irfan et al., 2021b). The highest value for VIF in this model is 2.478, which is far less than 5 (see **Table 4**), suggesting that our model is free from multicollinearity problems (Irfan et al., 2020b; Irfan et al., 2020c; Ahmad et al., 2021).

Model Fit

Model fit was examined using the three most widely used statistical techniques for SEM—the "standardized root mean

TABLE 2 | Mean, standard deviation, and discriminant validity using Fornell and Larcker's criterion.

S. No	Variables	Mean	SD	1	2	3	4	5	6	7
1	PCD	3.325	0.696	**0.820**						
2	ESB	2.402	1.201	0.749**	**0.757**					
3	ISE	3.021	0.542	0.745**	0.689**	**0.786**				
4	PBC	3.122	0.962	0.668**	0.740**	0.722**	**0.759**			
5	PEC	3.656	1.034	0.796**	0.673**	0.782**	0.712**	**0.830**		
6	PMB	2.111	0.113	0.631**	0.615**	0.612**	0.653**	0.669**	**0.853**	
7	PAE	3.405	0.265	0.740**	0.732**	0.785**	0.707**	0.711**	0.529**	**0.813**

Note: N, *511 **Correlation is significant at the 0.01 level,* $p < 0.01$; **Correlation is significant at the 0.05 level,* $p < 0.05$; *SD, Standard deviation; PCD, Perceived COVID-19 disruptiveness; ESB, Energy-saving behavior; ISE, Intention to saving behavior; PBC, Perceived behavioral control; PE, Perceived environment; PMB, Perceived monitory benefit; PAE, Positive anticipated emotion.*
These are the square root values of AVEs.

TABLE 3 | Heterotrait-monotrait ratio (HTMT).

S. No	Variables	PCD	ESB	ISE	PBC	PE	PMB	PAE
1	PCD	–						
2	ESB	0.822	–					
3	ISE	0.784	0.879	–				
4	PBC	0.846	0.665	0.785	–			
5	PEC	0.654	0.848	0.811	0.778	–		
6	PMB	0.762	0.780	0.755	0.856	0.803	–	
7	PAE	0.454	0.771	0.658	0.745	0.890	0.673	–

squared residual" (SRMR), "normed-fit index" (NFI), and goodness of fit (GoF) formula (GOF = $\sqrt{(AVE \times R^2)}$), where SRMR value should be ≤0.08 (Hu and Bentler, 1998) and NFI value should be between 0 and 1 (Bentler, 1990). However, a higher NFI value represents a better fit (Bentler, 1990). This study finds the value of SRMR is 0.077 and NFI is 0.617, suggesting our model is relatively satisfactory. Next, the GoF formula was used to calculate the model fit (Henseler and Sarstedt, 2013), where GOF = 0.1 advocates small, GOF = 0.25 represents medium, and GOF = 0.36 signifies large (Wetzels et al., 2009). We find the value of 0.528 for GOF in our model, demonstrating that the model surpasses the cut-off value for the large section.

Structural Model Assessment

Consequently, necessary measurement model assessment and model fit, the structural model analysis was performed. Bootstrapping evaluation of 5,000 resamples was used to analyze the importance of straight paths and test normal

TABLE 4 | Factor loadings of measurements model.

Constructs	Item	SFL	VIF	Cronbach α	CR	AVE
Perceived behavioral control	PBC1	0.719	1.228	0.729	0.802	0.575
	PBC2	0.727	1.211			
	PBC3	0.825	1.381			
Perceived environmental concerns	PEC1	0.862	2.329	0.848	0.898	0.689
	PEC2	0.806	1.767			
	PEC3	0.875	2.478			
	PEC4	0.773	1.602			
Perceived monitory benefit	PMB1	0.864	1.899	0.813	0.889	0.728
	PMB2	0.896	2.104			
	PMB3	0.797	1.595			
Intention to save energy	ISE1	0.773	1.659	0.793	0.866	0.618
	ISE2	0.852	2.048			
	ISE3	0.763	1.485			
	ISE4	0.753	1.444			
Energy-saving behavior	ESB1	0.774	1.531	0.760	0.842	0.573
	ESB2	0.623	1.350			
	ESB3	0.826	1.432			
	ESB4	0.789	1.599			
Positive anticipated emotion	PAE1	0.839	1.743	0.739	0.823	0.661
	PAE2	0.882	1.919			
	PAE3	0.707	1.268			
Perceived COVID-19 disruptiveness	PCD1	0.733	1.486	0.837	0.897	0.673
	PCD2	0.847	2.041			
	PCD3	0.845	2.009			
	PCD4	0.850	2.045			

Note: N, *511; CR = composite reliability; AVE, average variance extracted; SFL, standard factor loading.*

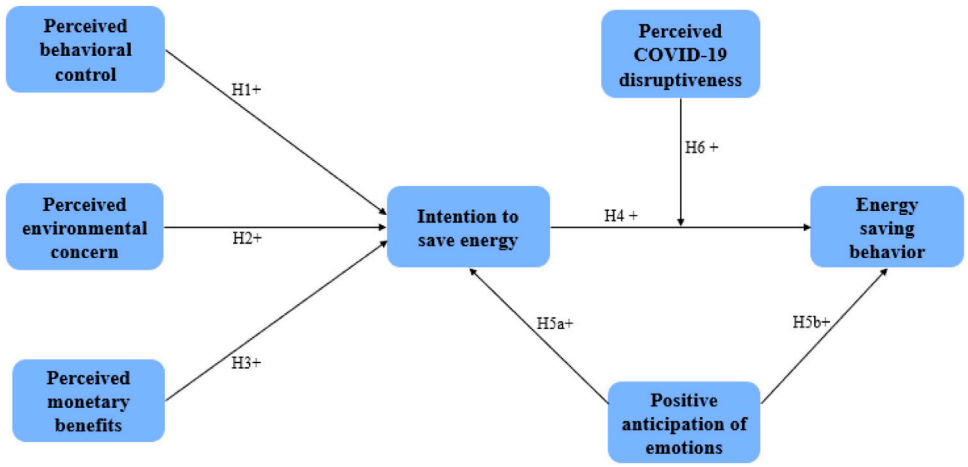

FIGURE 1 | Conceptual framework.

TABLE 5 | Hypotheses testing and specific indirect effects.

Hypotheses	B-values	p-values	t-values	Decision
H1: PBC →ISE	0.145	0.032	2.148	Accepted
H2: PEC →ISE	0.347	0.000	4.597	Accepted
H3: PMB →ISE	0.214	0.001	1.499	Accepted
H4: ISE →ESB	0.114	0.012	1.233	Accepted
H5a: PAE →ISE	0.395	0.000	6.526	Accepted
H5b: PAE →ESB	0.335	0.000	4.002	Accepted
H6: (PCD × ISE) →ESB	0.058	0.021	0.865	Accepted

faults. The results divulged a significant and positive influence of perceived behavior control (β = 0.145; $p < 0.001$), perceived environment (β = 0.347; $p < 0.001$), and perceived monitory benefit (β = 0.214; $p < 0.001$) on the intention to save energy, leading to the support of hypotheses H1, H2, and H3. Furthermore, the influence of intention to save energy on energy saving behavior (β = 0.114; $p < 0.001$) was found statistically significant and positive, confirming hypothesis H4. In addition, hypotheses H5a and H5b revealed a significant and positive influence of positive anticipated emotion on intention to save energy (β = 0.395; $p < 0.001$) and energy saving behavior (β = 0.335; $p < 0.001$). Thus, both are accepted. Finally, the perceived COVID-19 disruptiveness moderates the effect of intention to save energy on energy-saving behavior (β = 0.058; $p < 0.01$), confirming H6 only. Furthermore, perceived behavior control, perceived environment, and perceived monitoring benefit explains 73.3% of the variance in intention to save energy, while the overall model explains 63.6% variance in electric saving behavior, indicating a good model. **Table 5**; **Figure 2** provide the results.

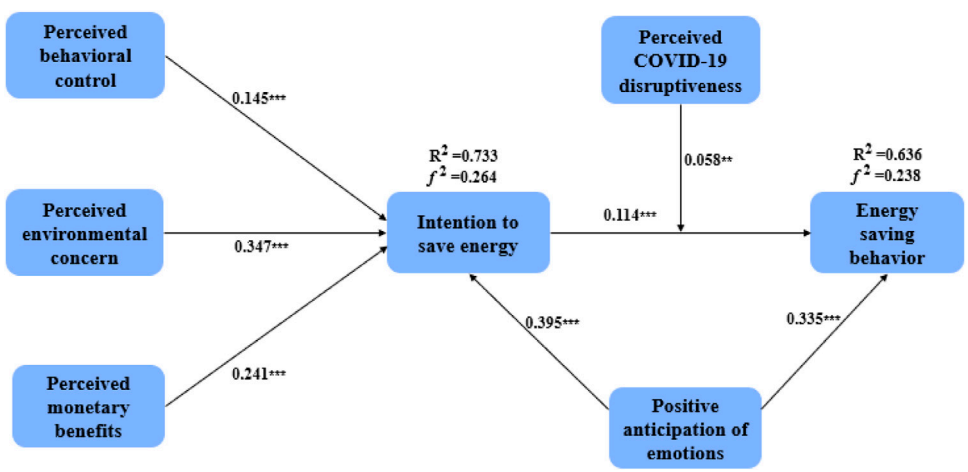

FIGURE 2 | Results of hypotheses.

DISCUSSION

Major Findings

According to the theory of planned behavior, this research investigates the influencing factors of residential ESB. We looked specifically at how cognitive factors influence residents' ISE and the moderating influence of COVID-19 disruptiveness on energy-saving intentions and behavior. SEM was employed to validate the hypotheses using survey data from 511 households in Pakistan.

The outcomes of this paper offer a meaningful theoretical contribution to the body of literature because limited research has been conducted on the relationship between intellectual factors and residents' ISE and ESB. The results indicate that perceived behavior control is positively and significantly associated with residents' ISE. These findings are consistent with past research on pro-environmental behavior, such as energy preservation and green buying (Klöckner, 2013; Webb et al., 2013; Cheung et al., 2016). In accordance with the prior research, Wang et al. (2018a) have also demonstrated that PBC has a positive effect on residents' understanding of energy conservation. Similarly, findings further suggest that PE and PMB are positively and significantly related to residents' intentions to save energy. These findings are consistent with the observations of Fu et al. (2021), as the authors discovered a significant relationship between perceived environmental concern, monitory benefits, and energy consumption behavior.

The study findings are also parallel to the theoretical foundations of TPB that propose a significant impact on perceived behavior and environmental control. From the TPB perspective, the results indicate that descriptive norms, environmental perception, information publicity, lifestyles, and perceived behavior control all significantly influence residents' energy-saving behavior. According to the TPB, residents' intention to preserve energy may be employed to significantly and positively predict household energy-saving behavior as a direct instrumental variable of energy-saving behavior. Furthermore, our study found a positive and significant impact of positive anticipate emotion on both ISE and ESB. According to the effective event theory, PAE is a powerful predictor of actual behavior because it creates a psychological desire for action (Weiss and Beal, 2007; Han and Hyun, 2018). In accordance with affective events theory, this study posits that PAE has a significant impact on residents' energy-saving intentions and behavior. These findings are also consistent with the research of Wang et al. (2018a), who suggested that PAEs have a strong association with residents' energy-saving behaviors.

The findings showed that there is a positive relationship between ISE and ESB. These findings fully consent to the research of Wang et al. (2018a), who suggested that power saving behavior is the act of shutting off when not needed, adopting high-efficiency energy, and investing in energy-saving technologies to reduce energy consumption. If the factors causing higher consumption were discovered before hitting the COVID-19 pandemic, adjustments might be more easily provided. Our research findings refer to the moderating role of perceived COVID-19 disruptiveness, which strengthens the relationships between residents' ISE and ESB. Because of the changing power consumption dynamics after the COVID-19 outbreak, energy consumption has significantly increased, caused by unexpected demands, resulting in high energy costs and energy losses.

Policy Implications

More importantly, this study makes policy recommendations to the Pakistani government for implementing ways to encourage inhabitants to save energy. According to the findings of this study, awareness about energy challenges, level of attention, perceived energy-saving control, and sense of responsibility are all characteristics that may be used in policy programs aiming towards reducing household energy consumption. Pakistani policymakers should focus on promoting public awareness of energy challenges such as excessive energy consumption and limited energy resources. Conventional energy infrastructure is increasingly being changed into computerized power generation due to the revolutionary advancement of Internet-based new technologies, the Smart home, artificial intelligence technology, and Big Data storage (Zhou and Yang, 2016; Renström, 2019). This will have a significant impact on home energy consumption behaviors. Well-designed education programs addressing the relevance of energy and environmental challenges and the advantages of energy conservation might be helpful. Policies and initiatives should also concentrate on establishing in residents a feeling of responsibility to conserve energy when it is unnecessary. It may be advantageous to implement energy-saving awareness campaigns and capacity-building initiatives. The government should also pay close attention to public relations and the media to educate communities that these energy and climate challenges can be handled if everyone works together. The focus could be given to hosting activities where everyone can share their expertise and experience with energy conservation. As a result, individuals' energy-saving knowledge will be increased, and energy-saving behavior will be promoted.

CONCLUSIONS

This study investigated the impact of cognitive and emotional factors on residents' ISE and their impact on ESB. We also investigated the role of perceived COVID-19 disruptiveness as a moderator between the relationship of ISE and ESB. The following key conclusions may be drawn based on the outcomes of this study: Firstly, the three perceptual elements have a strong influence. Both PMB and PE are positively and significantly associated with residents' intentions to save energy. Similarly, perceived behavior control has a significant and positive influence on residents' intention to save energy. Secondly, PAE has a positive and considerable effect on the ISE and the behavior to save energy. Similarly, the direct impact of ISE has a favorable relationship with the ESB. Finally, perceived COVID-19 disruptiveness has a significant moderating influence on the relationship between ISE and ESB.

The energy consumption differentiates between populations of southern and northern Pakistan due to variations in climate and resource distribution. This investigation primarily looked

into participants' intentions to save energy in their homes. Actual data on energy-saving behaviour would be beneficial. As a result, the upcoming research could delve further into the participants' actual energy-saving behaviour and assess the difference between energy-saving intention and actual energy-saving behaviour. Future studies should concentrate on northern cities and a broader group of residential users to capture more general findings. Furthermore, because all of the variables in this research were gathered by a questionnaire survey, the results might be biased by cultural pressures. As a result, researchers would be able to get more actual and precise energy consumption data for residents via energy meter bills in future studies.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

BA: Paper writing, MI: Data analysis, Writing-Review and Editing, MA: Proofediting and language, SS: Data analysis. All authors contributed to the paper and approved the submitted version.

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Factors Affecting Electric Bike Adoption: Seeking an Energy-Efficient Solution for the Post-COVID Era

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Sustainability think tanks such as the United Nations Organization have a strong focus on achieving economic and environmental sustainability goals globally. On the road to sustainable development, electric bike (E-bike) adoption is crucial. Nevertheless, research on the factors associated with E-Bike use, especially the psychological, financial, and capacity factors, has remained unexplored. This paper extends the theory of planned behavior with six novel factors related to individual choices to analyze E-bike adoption behavior. A sample of 507 Chinese bike riders is collected through the snowball sampling technique. The sample is estimated through structural equation modeling. The key findings are as follows: first, speed capacity, mileage capacity, and real-time camera positively drove E-bike adoption intention. Second, price differentiation negatively affected E-bike adoption intention. Third, the theory of planned behavior factors, including perceived relative advantage, cost savings, subjective norms, perceived behavioral control, and attitudes toward E-bike adoption, proved to be drivers of E-bike adoption intention. Finally, cost savings are the most critical factor of E-bike adoption intention, whereas perceived behavior control is the least critical factor. These results will help green transportation companies and emerging economies promote E-bike adoption to reach the environmental sustainability goals of the United Nations.

Keywords: environmental sustainability, financial factors, psychological factors, capacity factors, China, E-bike adoption

1 INTRODUCTION

Climate change mitigation and environmental sustainability are hotly debated concerns of modern economies (Ahmad et al., 2020b; Satrovic et al., 2021). The clean and renewable energy technologies have provided major breakthroughs to cope with the environmental hazards and climatic adversities (Irfan et al., 2019). In this regard, the transportation sector is renowned for heavily contributing to environmental pollution and climatic adversities (Irfan and Ahmad, 2021). To cope with such situations, green transportation has been considered an efficient way of reducing environmental degradation and improving human health. Most research has focused on electric vehicles for

achieving environmental sustainability. To this end, ride selection is an emergent lump in transportation research. One of the most environmentally friendly ride alternatives may be electronic bikes (E-bikes). In the 20th century, E-bikes in China improved rapidly. In 20 years, from 1998 to 2016, E-bike use increased at a rate of 64.8% per year. In addition to E-bikes, recent research of Luo et al. (2020) concerning a different type of environmentally friendly riding—bike-sharing—has been extensively oversupplied in Xiamen, China. Such a scenario is imperative for environmental sustainability because transportation generates one-quarter of the gas emissions in global energy utilization (McCollum et al., 2018).

Compared to E-bikes, other types of bikes may not be superior options for meeting the environmental sustainability goals. For example, Pal and Zhang (2017) found that even shared bikes might generate harmful externalities. This kind is still a sustainable transportation approach. However, bike delivery is performed by trucks/vans, and fossil fuels create gas emissions. In addition to speeding behavior, Truong et al. (2020) reported that 16% of motorcycle drivers were involved in accidents, which is higher than E-bike riders or other drivers. Undoubtedly, several studies have been performed on E-bike speed and risk behavior. However, most studies excluded personal rides. For example, in China, although E-bike riding is high, most accidents take place among bike delivery riders. Although the United Nations Organization (UNO) and China value E-bike use, in other countries such as Bangladesh, motorcycle riders have increased by 7.45% for different reasons (Wadud, 2020). Green energy adoption depends on cost, emotional dimensions, societal perception, and conditional dimensions (Jabeen et al., 2021a). Studies focusing on bike riders' adoption attitudes would be a hot issue for different countries to increase green transport energy consumption.

The above literature represents the comparative aspects of E-bike adoption. Our study has unique points. The psychological factors related to the comparison of E-bike and motorbike adoption have not previously been explored. Furthermore, the comparison of riders' feelings about capacity factors provides great insight into the decisions underlying the individual's psychology about economic factors.

Relying on one type of transportation for populated cities may not be sustainable (Ahmad and Khattak, 2020; Adedoyin et al., 2021; Ahmad et al., 2021b). China, a developed and populated country, has no energy crisis. Therefore, E-bike companies and users could increase their role in achieving the goals of sustainability. In China and 50 other countries up until October 2019, 2,080 schemes of bike-sharing and 360 further plans were in operation. Comparing E-bikes with other kinds of riding options, riders might make psychological distinctions. Riders decide on the basis of psychological factors; in China, the factors that influence their behavior would be different from those in the last 3 or 5 years. After the purchase of E-bikes, riders' psychology changes to ask if the battery is safe from thieves. The most expensive thing in an E-bike is the battery. The second adoption factor, financial issues, is designed on the basis of price differentiation and cost savings. Financial factors, after and during the purchase process, involve which kind of bike would provide short-term financial benefits. The reasons involve rider decisions based on price differentiation. Third, the rider's adoption behavior is also due to E-bike capacity compared with that of motorbikes. On a motorbike, drivers can meet petrol needs at every step. Therefore, their ride behavior may not be related to their fuel demand in normal situations. However, E-bike riders know that low or normal speed and battery capacity can increase their mileage capacity.

China leads the world in various kinds of E-bike transport (Fishman and Cherry, 2016). For transport sustainability, different kinds of E-bikes and transportation would help to accomplish the country's objectives. However, research studies on the adoption of E-bikes are lacking, particularly in emerging populated countries where there are no current research studies. The most important call for E-bike adoption is the comparative study of behavior at the individual level. Research on sustainable transportation in different emerging countries has mainly investigated adoption decisions in the following directions: 1) non-adoption of eco-friendly bikes in Johannesburg (Wood, 2020); 2) E-bike adoption boosted environmental sustainability in the Netherlands (Sun et al., 2020); 3) E-bike ownership significantly minimizes the use of other transport facilities (Kroesen, 2017); 4) recently, Simsekoglu and Klöckner (2019) suggested quantifying e-bike rider comparisons and their adoption to identify the impact on further transportation approaches; and 5) E-bike riders were more careful about safety measures than different road users (Wang et al., 2019). Comparatively, new research on the sparkling vicinity of E-bike adoption has basically continued unchanged. Similarly, because of lack of existing knowledge about Chinese users' E-bike adoption, many countries may seek to understand the motives for E-bike adoption at the personnel level and governments seek to accomplish and adopt the strategies used by the Chinese government. There is interest in achieving the United Nations sustainability goals through changing individual psychology and developing comparisons of transportation opportunities to promote bike riders for responding to the demand for environmentally friendly transportation techniques.

This paper scientifically establishes and investigates the role of rider's intention to adopt E-bikes with selective attention on 1) a comparison of bike adoption on the basis of price differentiation, 2) a comparison of the cost savings of using the bike for 3 or 5 years of personnel use, 3) the perceived relative advantage of E-bikes and their effect on adoption behavior, 4) the reasons behind the thinking about E-bike safety and real-time camera effects to overcome the psychological factors, and 5) individual thoughts about speed capacity differences and its role in adopting the E-bike. Last, mileage capacity impacts the adoption of E-bikes. In addition, Ru et al. (2018) examined attitudes and experiential attitudes with the help of the theory of planned behavior (TPB). However, compared with earlier researchers, our current research has measured newly emerging areas of research. Comparatively, no studies have been conducted on new technology differences in E-bike adoption, proficient compensation of E-bikes, and effects on E-bike adoption. Hence, this study added interesting new knowledge by filling these prominent gaps. Therefore, to check the theoretical model, primary data of 507 E-bike Chinese riders

from different cities were used. We developed the original conclusion formed on the smart PLS structural equation modeling (PLS-SEM) approach by applying an online survey questionnaire. The core result of the analysis proved that bike adoption needs to improve in four different categories. The user response to the conditions to obtain individual intentions was the promising effect of transforming their behavior from petrol bikes to E-bikes. The research findings provide the empirical basis to develop a strategy proposition for companies and governments to boost sustainable planning, especially in areas of less E-bike use.

In addition, our study has new comprehensive findings compared with previous research. For example, individual adoption aspects and transportation choices or preferences have not been previously studied. Coupled with this, personal decisions on the basis of individual psychology are deficient. Similarly, emerging matters related to financial paybacks at the individual level in the behavioral structure of the TPB in the energy sector have remained sparse. In short, the present research produces innovative findings compared with previous research.

Regarding the application of our results, the main conclusions are found through the survey of Chinese riders, but the explanations of rider intentions and those factors that influence adoption behavior of the E-bike sustainable transportation choice can be provided as lesson learned strategies. According to this view, the Chinese government can also implement it in their future planning division to improve the levels of sustainable transport. In addition, emerging countries can implement these interesting results to improve adoption behavior. Importantly, psychological factors provide relevant directions for undeveloped countries with energy problems and could be implemented on a short-term basis or just in capital cities (Abul and Satrovic, 2021; Ahmad et al., 2021c). Dual factors related to financial aspects could be implemented in educational institutes by countries experiencing energy crises (Ahmad et al., 2018; Ahmad and Zheng, 2021). Here, accelerating the comparison of our study will also help to implement sustainable policies. Moreover, the PLS-SEM approach in this essential case is the most appropriate methodology because it can help measure attitude preferences and compare unobserved research variables.

The remainder of the research work is organized as follows: *Theoretical Framework and Hypothesis Development* describes the theoretical framework and hypothesis development; *Data and Analyses* presents the data and analyses; *Results and Discussions* explains the results and discussions; finally, *Conclusion and Policy Implications* presents the conclusions, research limitations, and future research directions.

2 THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

2.1 Theory of Planned Behavior

Prominent researchers are paying attention to the need to understand the user decision process to adopt emerging sustainable selections at different levels. The user decision process has various comprehensive features. The TPB (Ajzen, 1991) highlights social, psychological, and socioeconomic factors. Various theoretical models are proposed in the decision-making process. However, TPB is better developed compared with other models because it is an improved form of the theory of reasoned action (TRA). At present, several researchers have compared TPB with other theories. Recently, comparative research by Hollett et al. (2020) and Jabeen et al. (2019a) found the TPB to be a suitable research model to explain intentions and behavior. In addition, Irfan et al. (2021a) applied it to assess the face mask adoption intention of consumers. In addition, in his book (Ajzen, 1991), Ajzen revealed that "Individual available information mediates the effects of biological and environmental factors on behavior." It shows that TPB can facilitate the prediction of user intentions toward a form of particular transportation. We adopted the TPB approach considering these important aspects. First, the comparative TPB points include the best measurement through accepted behavior of the alternatives in shaping the selection, which means that psychological factors need to be considered (Ajzen, 1991). Second, we identified three major points of the model: 1) "attitude" that a person observes and believes, 2) "subjective norms" of what will be the social impact if a person follows the points or adopts the opportunity, and 3) "perceived behavioral control" means how individuals feel about ease of use or difficulty in adopting. In the energy sector, Jabeen et al. (2021a) mentioned the adoption of sustainable resources from a different perspective, recommending the TPB (Neto et al., 2020) as an approach to understand the selection of different transportation options. Fourth, to the best of our knowledge, no studies have extended the TPB to predict E-bike riders' attitudes and their role in achieving the UNO sustainability goals. Our modified theoretical framework is presented in **Figure 1**.

2.2 Hypothesis Development

2.2.1 Perceived Relative Advantage

"The degree to which an innovation is perceived as being better than the idea it supersedes," defined by Rogers (2003), is simply the degree of improvement from the previous level of a product or technology (Moore, 1991). This is important because, currently, the results by Edge et al. (2020) proved that more research is needed to better understand e-bikes and to develop clarity on acceptable use at city scales. E-bikes might be the first and final significant achievement due to the perceived relative advantage. On the basis of research opinions and to answer the abovementioned needs, the first hypothesis is formulated as follows:

H1: Perceived relative advantage is expected to positively affect E-bike adoption intentions.

2.2.2 Real-Time Camera

In the Netherlands, van den Berg et al. (2020) verified that the safety perception and the social environment have an effect on satisfaction. In Singapore, a significant increase in cycling behavior was observed due to improving the cycling network (Zhou et al., 2020). Rider psychology and battery safety might have a large role in adoption. Therefore, the gap between the actual and perceived safety and security issues by bikers needs to

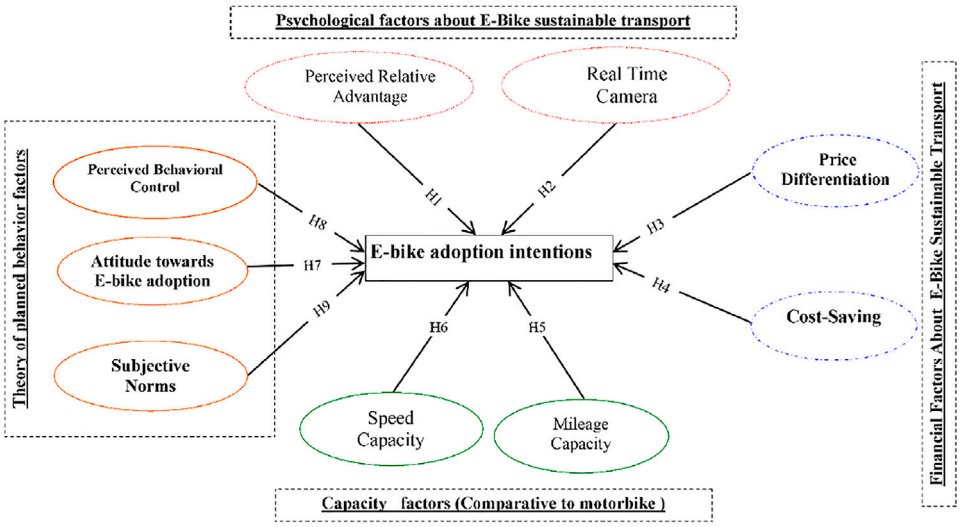

FIGURE 1 | Extending the theory of planned behavior for factors affecting E-bike adoption intention. Source: Modified from Jabeen et al. (2019b).

be addressed. Perhaps some riders do not select bikes if they feel unsafe about batteries and bikes. However, recently, 3 years of improvement or safety changes in China might have influenced massive E-bike adoption. The camera structure for bike safety includes social structure improvement, and Hawley et al. (2020) found that social influence has a significant psychological effect on a structural approach for future adoption. The government should focus on public acceptance and safety concerns (Roh and Kim, 2017). Therefore, these interesting findings helped us to formulate the second unique hypothesis:

H2: Real-time camera features are expected to positively affect E-bike adoption intentions.

2.2.3 Price Differentiation

Price differentiation refers to the purchase cost at present choice. First, we aimed to relate the factors of financial pull and E-bike adoption psychology. Riders might choose something best compared with the price of other alternatives. This interesting concept related to the relationship between costs and cognitions has been discussed in the research of Kurzban et al. (2013). They projected that an individual's efforts could inspire the selection by giving importance to the purchasing cost (Stavrakas et al., 2019); green adoption and financial planning have shown that retail price and cost affect solar power adoption.

Updated research has focused on E-bike pricing and new opportunities. Currently, Fyhri et al. (2017) mentioned that a price strategy could increase e-bike user trends, for example, tax reductions. However, research is lacking about the benefit of price differentiation and the cost benefits. Research about price differentiation is needed, as Eccarius and Lu (2020) pointed out about cost awareness knowledge. What kind of awareness improves adoption should be better understood; awareness of the purchasing cost can be a solid reason for decision-making. The authors investigate a costing mock-up and how it affects the rider's financial intentions through E-bike adoption psychology.

H3: Price differentiation is expected to affect E-bike adoption intentions negatively or positively.

2.2.4 Cost Saving

For a comparative study, business research shows a significant difference at the management and innovation levels (Roth Cardoso et al., 2020). Therefore, companies or government plans for E-bike promotion are core decisions. The daily marginal cost or daily cost savings might play a role in adoption psychology. During purchase decisions, cost savings might be a key plan for E-bike adoption, as well as proof that customer satisfaction increases cost-saving psychology (Van Poucke et al., 2016). In addition, the achievement of cost savings is a short-term goal of the customer (Schiele, 2007). Therefore, the fourth hypothesis is formulated as follows:

H4: Cost savings are expected to positively affect E-bike adoption intentions.

2.2.5 Mileage Capacity

Mileage capacity is important for traveling. König and Grippenkoven (2020) verified that long travel times are a huge usage barrier. Similarly, 70% of the respondents had a 12-km range from the university on e-bike trips (Nematchoua et al., 2020). As studies confirmed, the first selection for short distances might be E-bikes. Mostly, E-bike use depends on perceived usefulness (Wolf and Seebauer, 2014). Mileage capacity is an important factor in adoption psychology. Advancing the 100-km capacity of E-bikes will impact purchase decisions and, thus, is very important to know. A total of 72.0% confirmed that E-bikes generally substituted conventional bikes (Van Cauwenberg et al., 2019). However, mileage capacity should not be a barrier in E-bike adoption because the threshold mileage capacity was 5.1 km in Spanish bike users (Chillón et al., 2016). The reason for this may be that battery capacity is much better than it was a few years ago.

With these findings, comparative research contributes to the development of the fifth hypothesis as follows:

H5: Mileage capacity is expected to affect E-bike adoption intentions.

2.2.6 Speed Capacity

Interestingly, Bai and Sze (2020) compared two kinds of rides and proved the difference during the red light crossing tendency. There might be different perceptions about speed for E-bikes and motorbikes. Ellison and Greaves (2015) explored whether drivers would like to increase their speed to save time. However, transportation in China has recently improved considerably. Therefore, there might be psychological changes. Speed capacity as a research variable tries to answer these changes and their effects on adoption behavior. Importantly, quick accelerations cause travelers to slide (Schau and Masory, 2013). Recent research has mainly investigated these matters: for E-bikes, the average speed is approximately 16 km/h; and the maximum riding speed cannot exceed 30 km/h (Cherry and Cervero, 2007). Our research incorporates E-bikes and motorbikes. Different kinds of transportation opportunities have been developed in recent years. Therefore, to understand the relationship of speed capacity and adoption behavior, the sixth hypothesis is formulated as follows:

H6: Speed capacity is expected to positively or negatively affect E-bike adoption intentions.

2.2.7 Attitudes Toward E-Bike Adoption

Attitude refers to a person's positive thinking about behavior. Currently, Jamšek and Culiberg (2020) found the relationship between "perceived sustainable usefulness" and the technology acceptance model. Bike quality influences perceived sustainable usefulness, and use loyalty advances their proposed idea. We try to forward this research by improving the level of an individual's attitude by linking it with E-bike green sustainable transport. E-bike users' findings by Zhang et al. (2020b) confirm that attitude followed by innovativeness is the most imperative predictor. However, adoption psychology and attitude studies still do not exist. Importantly, Ajzen and Fishbein (1970) conduct a comparison of the theory of value–belief–norms and TPB for environmental change and adaptation behavior, but the E-bike adoption model is lacking. In particular, China is leading in electric vehicle improvements. Important new findings by Zhang et al. (2020a) relating to E-bikes suggest that they offer maximum satisfaction compared with other transportation modes. Attitude can be improved with different strategies. This mentioned importance of attitude and its improvements encourage us to formulate the seventh hypothesis as follows:

H7: Attitude toward E-bike adoption is expected to positively or negatively affect E-bike adoption intentions.

2.2.8 Perceived Behavioral Control

Individuals' confidence in their personal capacity to engage in behaviors is called perceived behavioral control (PBC) (Ajzen and Fishbein, 1970). PBC directly affects behavior. The required intentions could not be shaped if individuals had no confidence in performing any behavior. At the country level, Chinese users might think more about PBC because the most successful way to decrease carbon emissions in transport is fuel switching behavior (Zhang et al., 2020a).

H8: Perceived behavioral control is expected to positively impact E-bike adoption intentions.

TABLE 1 | Demographic data.

Classification		Frequency	Percentage %
Gender	Male	305	60.15
	Female	202	39.84
Marital status	Married	296	58.38
	Unmarried	154	30.37
	Divorced	57	11.24
Age	Under 18	17	03.35
	18–30	206	40.63
	31–40	191	37.67
	41–50	67	13.21
	Above 50	26	05.12

2.2.9 Subjective Norms

Subjective norms (SNs) are clarified by Ajzen (1991) as the perception of the society about adopting an alternative or selection for personnel use. In the society, family, friends, or colleagues may be inspired to adopt the E-bike. These inspiration sources were also mentioned by Jabeen et al. (2019a) regarding the adoption of new green technologies, which depends on the energy sector reforms and energy efficiency plans (Demirbas et al., 2017) to impress the public. In Chinese culture, Yang et al. (2020) verified that situational factors impact green behavioral awareness and intention. On these bases, to address the research gap, the ninth hypothesis was formulated as follows:

H9: Subjective norms are expected to impact E-bike adoption intentions.

3 DATA AND ANALYSES

3.1 Data Collection and Description

The questionnaire items for the perceived relative advantage were taken with a minor modification from Moore (1991) and Wang et al. (2018a). The perception of the role of the real-time camera was adopted from Klobas et al. (2019) with a minor modification. Price differentiation was adopted from Carter and Jennings (2004) and Wang et al. (2018b); cost savings from Meuter et al. (2000); speed capacity from Saleem et al. (2018); PBC from Halder et al. (2016); SNs from Kardooni et al. (2016) and Turel (2016); attitudes from Yang et al. (2016); and E-Bike adoption intention from Ahmad et al. (2017), Asadi et al. (2021), and Paul et al. (2016). Overall, five questions were deleted in the analysis due to less overloading. The detailed questionnaire items are presented in **Supplementary Appendix Table SA1** (see Supplementary Materials). The demographic data are reported in **Table 1**.

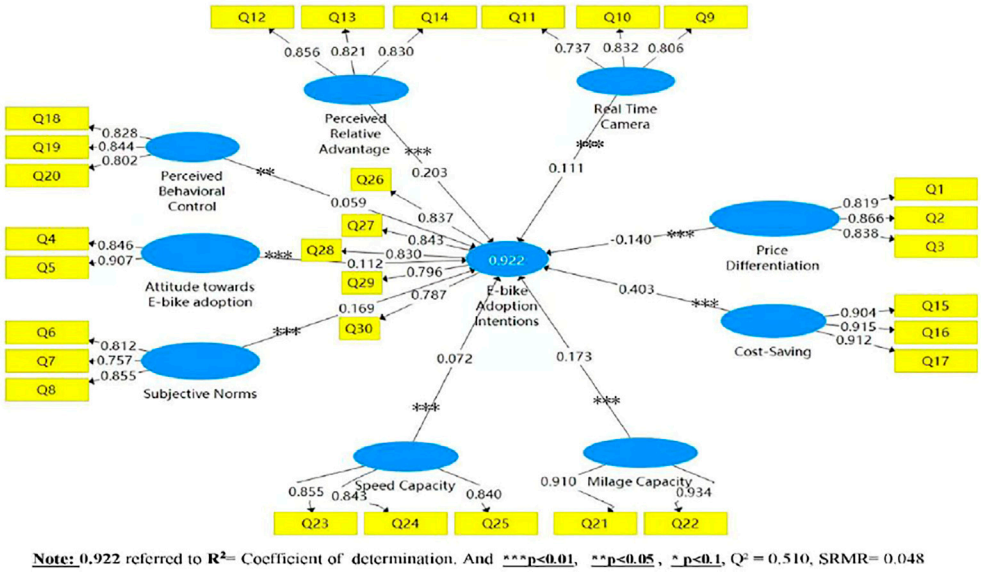

FIGURE 2 | Structured model results (PLS extracted).

3.2 Data Analysis Overview

Smart PLS-SEM has played a superior role since 2013. Unfortunately, PLS-SEM has insufficient use in green energy transportation adoption to explore the benefits through this novel approach. Traditional studies used the covariance-based SEM (Jöreskog, 1979). However, we apply PLS-SEM because it is suitable for a small sample size (Wong, 2010); we used PLS to explain the research objectives, as it shows a higher power of statistical explanation of the variables than CB-SEM. PLS-SEM includes advanced bootstrapping techniques and is not an alternative to CB-SEM but a "complementary modeling approach" toward the SEM technique (Hair Jr et al., 2021), and prediction power is significantly better (Sarstedt et al., 2016). The past studies also considered other probability methods such as Probit and Propensity Score Matching (Jabeen et al., 2020); however, because of flexibility of application, we have used CB-SEM technique. This technique is used in energy adoption and acceptance, e.g., acceptance and renewable energy utilization (Irfan et al., 2020; Jabeen et al., 2021b; Fatima et al., 2021) and willingness to use solar energy (Irfan et al., 2021b).

3.3 Assessment of Measurement Model

Primarily, we verified the data analysis through convergent validity and discriminant validity to attain the measurement model basics. Actually, the convergent validity of the measure demonstrates the strength or power level of the items with theoretical relevance of the factors. Following the work of Anderson and Gerbing (1988), a composite reliability (CR) assessment was used to investigate the internal consistency of the variables.

Previous research regarding CR, rho indices = 0.7 (Dijkstra and Henseler, 2015) and AVE > 0.5 (Chin, 2010); importantly, the AVE square root value of every construct was higher than the value of the construct correlation (Fornell and Larcker, 1981). Our analysis shows values of factor loading >0.707 (Hair et al., 2011). **Figure 2** and **Table 2** also show outer loading. Values were more than the compulsory standard requirements or standards (Schuberth et al., 2018). In **Tables 2** and **3**, Cronbach's alpha was sometimes not used for the reliability test because it is not suitable for the PLS-SEM, as suggested by Gadermann et al. (2012), but our results were accurate, indicating that the response was good in the questionnaire. In addition, as important criteria, the correlation values between the constructs were less than the self-correlation of each construct, which is consistent with the proposition of Kline (2015) and Hair Jr et al. (2021).

3.4 Assessment of Structured Model

Bootstrapping is an algorithm technique to apply small sample analysis on a large-scale sample. The bootstrap replication number can fluctuate from 500 to 5,000. The hypothesized relations linking the constructs of the planned, structured model were checked by bootstrapping (3,000 resamples) to obtain the confidence intervals and variable t-values (**Table 4**).

The bootstrapping technique is suitable for small sample volumes because it does not depend on the normality conjecture (Sardianou and Genoudi, 2013). To conclude, the bootstrapping technique was used to calculate the estimated accuracy of the measurement model, as suggested by Hair Jr et al. (2021).

As mentioned by Stone (1974), the prediction power for the structure model was confirmed by investigating the coefficient of determination (R^2), which indicates the collective effect of exogenous (independent) variables on endogenous variables (dependent variable). The R^2 can measure the level of variation in the dependent variable highlighted in the explanatory (independent) variables in the model. R^2 = 0.25,

TABLE 2 | Reliability and validity of measurement scales.

Constructs	Item	Outer loading	Mean	SD	Alpha	CR	AVE
Attitude toward E-bike adoption	ABA-1	0.846	0.768	0.020	0.703	0.869	0.769
	ABA-2	0.907					
Cost saving	CS-1	0.904	0.827	0.019	0.897	0.935	0.829
	CS-2	0.915					
	CS-3	0.912					
E-bike adoption intentions	EAI-1	0.837	0.670	0.018	0.877	0.910	0.670
	EAI-2	0.843					
	EAI-3	0.830					
	EAI-4	0.796					
	EAI-5	0.787					
Mileage capacity	MC-1	0.910	0.851	0.018	0.825	0.919	0.851
	MC-2	0.934					
Perceived behavioral control	PBC-1	0.828	0.679	0.025	0.767	0.864	0.680
	PBC-2	0.844					
	PBC-3	0.802					
Price differentiation	PD-1	0.819	0.706	0.026	0.794	0.879	0.707
	PD-2	0.866					
	PD-3	0.838					
Real-time camera	RTC-1	0.86	0.626	0.028	0.719	0.835	0.628
	RTC-2	0.832					
	RTC-3	0.737					
Perceived relative advantage	PRA-1	0.856	0.697	0.021	0.784	0.874	0.699
	PRA-2	0.821					
	PRA-3	0.830					
Speed capacity	SC-1	0.855	0.714	0.027	0.802	0.883	0.716
	SC-2	0.843					
	SC-3	0.840					
Subjective norms	SN-1	0.812	0.653	0.022	0.737	0.850	0.655
	SN-2	0.757					
	SN-3	0.855					

TABLE 3 | Discriminant validity.

	1	2	3	4	5	6	7	8	9	10
1. Attitude toward E-bike adoption	**0.877**	–	–	–	–	–	–	–	–	–
2. Cost saving	0.843	**0.91**	–	–	–	–	–	–	–	–
3. E-bike adoption intentions	0.807	0.818	**0.819**	–	–	–	–	–	–	–
4. Mileage capacity	0.567	0.413	0.653	**0.922**	–	–	–	–	–	–
5. Perceived behavioral control	0.568	0.434	0.592	0.383	**0.825**	–	–	–	–	–
6. Perceived relative advantage	0.668	0.548	0.797	0.545	0.553	**0.836**	–	–	–	–
7. Price differentiation	0.555	0.464	0.539	0.391	0.798	0.471	**0.841**	–	–	–
8. Real-time camera	0.644	0.555	0.708	0.468	0.709	0.622	0.760	**0.792**	–	–
9. Speed capacity	0.496	0.381	0.563	0.391	0.74	0.533	0.749	0.659	**0.846**	–
10. Subjective norms	0.725	0.580	0.812	0.538	0.568	0.765	0.482	0.658	0.557	**0.809**

Bold values indicate the square root of the average variance extracted.

0.50, and 0.75 refer to weak, moderate, and strong predictive power, respectively. Our R^2 was 0.922 (**Figure 2**). Comparatively, for further software, the R^2 value (0.75) entails significant understanding while exceeding 0.35, the threshold value suggested by Ketchen (2013).

All the independent variables indicated a significant positive effect on the dependent variable, except for the (H3) price differentiation on the intentions. For p values, only H8 PBC has $^{**}p < 0.05$, indicating that it is not highly significant but has a sufficient significance level (**Table 4** and **Figure 2**).

The next compulsory step, the value of Q^2, defined as a measure of cross-validated redundancy, is estimated to determine all planned constructs; the analysis proved that our structural model has a significant predictive level. Following the suggestion of Stone (1974) and Geisser (1974), the values of Q^2 were used to confirm the predictive relevance and validity of the model. Q^2 can estimate the predictive validity of the large and multipart PLS model through the blindfolding technique. We calculated it through the blindfold bootstrapping technique (**Figure 2**).

TABLE 4 | Structured model and variables direct effects.

Hypothesis	Relationship	Direct effect	t-value	Decision	f^2
H1	PRA→EBAI	0.203***	6.839	Accepted	0.188
H2	RTC→EBAI	0.111***	4.261	Accepted	0.047
H3	PD→EBAI	–0.140***	4.329	Accepted	0.059
H4	CS→EBAI	0.403***	15.328	Accepted	0.572
H5	MC→EBAI	0.173***	11.986	Accepted	0.230
H6	SC→EBAI	0.072***	3.205	Accepted	0.023
H7	AEBA→EBAI	0.112***	3.840	Accepted	0.028
H8	PBC→EBAI	0.059***	2.264	Accepted	0.013
H9	SN→EBAI	0.169***	6.449	Accepted	0.108

*EBAI, electric bike adoption intention; PBC, perceived behavioral control; SN, subjective norms; SC, speed capacity; CS, cost savings; PRA, perceived relative advantage; RTC, real-time camera; PD, price differentiation; MC, mileage capacity; AEBA, attitude toward E-bike adoption. Asterisks of * mean *p < 0.1, ** p < 0.05, and *** p < 0.01 indicate significance level or p-value strength.*

Cohen (2013) proposed f^2 to verify the degree of input by independent or exogenous variables in terms of f^2 to explain the independent or endogenous variable. Criteria of 0.02, 0.15, and 0.35 are referred to as weak, moderate, and strong effect sizes of the research constructs, respectively. In particular, the f^2 value was large (CS→EBAI, f^2 = 0.572, exceeds 0.35), which showed a large effect between cost savings and E-bike adoption intention. There was a moderate effect between mileage capacity and E-bike adoption intention (MC→EBAI, f^2 = 0.230, exceeds 0.15) and between perceived relative advantage and E-bike adoption intention (RD→EBAI, f^2 = 0.188, exceeds 0.15). The f^2 values met the base level criteria of 0.02 in the case of the remaining relationships (**Table 4**).

The standardized root mean square residual (SRMR) as per Henseler et al. (2016) can be applied as a goodness of fit in PLS-SEM to avoid misspecification in the research model. The value of SRMR was acceptable (Hu and Bentler, 1999). This shows how that the set of variables is a good fit for the model.

3.5 Importance–Performance Map Analysis

Importantly, Ringle and Sarstedt (2016) and Hair Jr et al. (2021) suggested the use of importance–performance map analysis (IPMA). According to them, IPMA is a valuable analysis technique in PLS-SEM to broaden the typical results covering the path coefficient estimates through the addition of dimensions that consider the average rate of the latent variable. **Figure 3** illustrates the results of the IPMA, showing that speed capacity demonstrated the highest performance, whereas mileage capacity depicted the lowest performance. Most importantly, cost savings proved to be the most important factor, whereas PBC exhibited the least importance (**Figure 3**).

4 RESULTS AND DISCUSSIONS

Chinese data were analyzed about significant adoption factors for E-bikes. Current research based on the TPB theoretical framework presented an overall theoretical extended framework to successfully clarify the role of the human psychological role in a deep sense of financial, capacity, and conditional psychological factors. Consequently, our study correlates at an advanced level with Rankavat and Tiwari (2020) and Ahmad et al. (2020a); as questioned, planners and researchers must consider e-bike risk observations. Finally, two psychological factors, i.e., perceived relative advantage (H1) and the role of the real-time camera (H2), were included in our study.

A real-time camera is a solution to the barrier to E-bike adoption. Thus, our model responds to the advanced level for the mentioned barrier to adoption.

Concerning the financial perception (H3 and H4) and capacity factors (H5 and H6) of the bike, Lehr et al. (2020) confirmed that user involvement could increase intentions, but how? Therefore, parallel to their suggestion of using information integration theory, our study also supports that Chinese policies should try to offer the maximum unintended trial by explaining our research insights. Green energy adoption in developing countries is important for anti-poverty policies (Rahman et al., 2021) and for achieving extra savings in the case of emerging countries (Gelani et al., 2021).

Concerning financial perceptions, an important factor regarding cost savings has an impact on E-bike adoption. It is

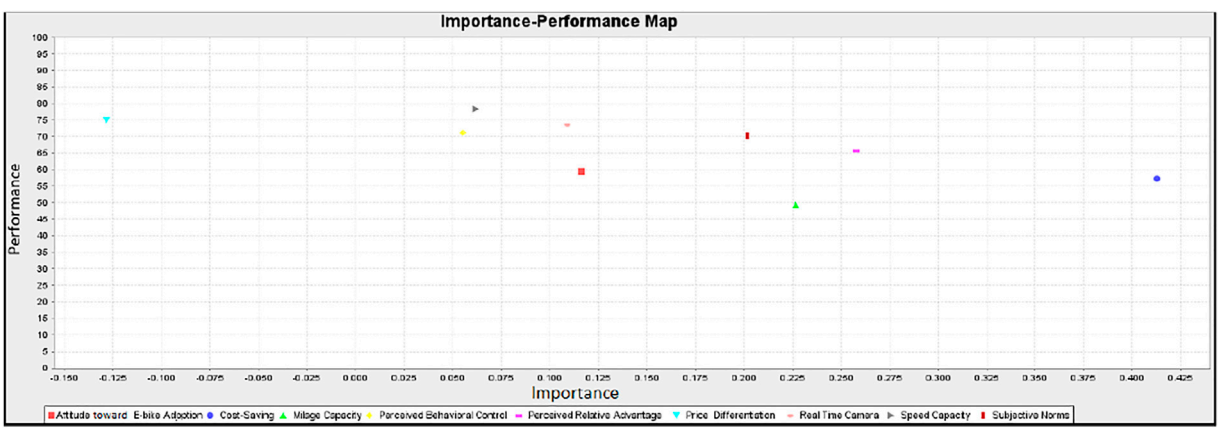

FIGURE 3 | Importance–performance map analysis (IMAP).

a targeted effort by an E-bike purchaser. Bike adoption and experiences can improve an individual's daily basis cost savings. With the mentality of improvement, these experiences can be enhanced with increasing sustainable transportation.

Cost savings and PBC are parallel forward solutions for previous research by Gao et al. (2021), in which monetary rewards can motivate citizens to engage in bike-sharing. Predefined energy subsidies helped minimize costs (Matosović and Tomšić, 2018). Therefore, riders are more likely to adopt E-bikes with the help of cost differentiation, cost savings, and PBC. For Chinese users, the price at the time of purchase was not an explanatory factor of E-bike adoption. This may be because the E-bikes had almost the same price as petrol bikes or, perhaps, due to being one of the richest countries in the world.

Importantly, for capacity comparisons, our study tries to provide a solution for road safety. As Mao et al. (2021) mentioned through big data, long drives and peak-hour driving are the main reasons for accidents. Therefore, we proved that the E-bike was a good solution compared with motorbikes because E-bike users need bikes for a maximum of 100 km in 2 days' usage and speed capacity from 20 to 30 km/h. In China, long drives, subways, and other sources are good enough for our sampling areas, similar to findings in the Canary Islands in Spain in terms of the factors of distance and cost (Maas et al., 2020).

Capacity comparisons (H5 and H6) are advancing the research on E-bikes by Makarova et al. (2016) as "fun and different to drive on." Therefore, adoption psychology for companies could use our model to follow in practical research to advance E-bike transportation. We advanced their model; an important reason is that these kinds of studies have proven that E-bikes are better than other bikes in driving modes.

Speed capacity is a different scenario. Wager et al. (2016) confirmed that, if an electric vehicle is driven for a long distance at a high speed, then it consumes more energy. In parallel, perceived relative advantage, attitude toward adoption, mileage capacity, and speed capacity are also considered relevant factors. Because a small improvement in vehicles' weight or speed greatly impacts the mileage capacity, comparatively, electric cars have a larger energy storage capacity or a larger fuel tank. Very importantly, in China, E-bikes have shown yearly improvements in relative advantages compared with other riding alternatives.

Our sample-based model is extended and has been supported by Nematchoua et al. (2020); their results on E-bikes show they produce maximum satisfaction compared with other transport modes. In their sample, 70% of riders living in the 12-km range agree to ride e-bikes. Mileage capacity and attitude (H7) were entirely supported by their concepts and confirmed the research. However, little is known about the relationship between adoption psychologies. By following the multimediation approach of Yasir et al. (2020) about awareness, the government and companies should advertise based on our model. First-ever benefits, e.g., improvement in perceived relative advantage, will increasingly convince users to adopt E-bikes. The findings are comparable to those of Michas et al. (2020), who suggest the implementation of active adaptive policies by focusing on short-term and long-term perspectives to support adoption behavior.

5 CONCLUSION AND POLICY IMPLICATIONS

Environmental sustainability is the prime concern of global economies to avoid climatic adversities in the future. In this regard, enhancing sustainable transportation, such as E-bikes, would significantly contribute to environmental protection. Our insights provide a significant addition to E-bike research by ride selection psychology in China and the appropriate TPB extensions for an alternative ride category. We concluded that adoption behavior would positively depend on an individual's perception of financial benefits through cost savings; however, it negatively relied on cost differentiation. In addition, the significance of individual psychology through the role of perceived relative advantage shows the improvement of E-bikes compared with other rides. Moreover, speed capacity and mileage capacity were addressed for the first time and proved to be positive E-bike adoption factors. Further focus on driving factors and the elimination of impediments to E-bike adoption will not only contribute to sustainable transportation but will also enhance its contributions to environmental sustainability globally, with the extreme need for other counties to follow China's green investment policies (Ahmad et al., 2021a).

Our proposed idea with theoretical support will provide a new direction for research on the adoption of E-bikes. However, there are some potential limitations to be addressed by future studies. First, this research examined the different determinants, such as psychological factors, in the safety of E-bikes and their batteries and perceived relative advantages over other kinds of bikes. In addition, it included financial factors, capacity factors, and TPB factors. It was challenging to add more adoption factors due to statistical suggestions and to complete the study's analysis without bias. Therefore, future studies should include other factors, such as different kinds of E-bikes (e.g., pedal bikes and without pedal bikes), transiting factors, and other bike capacity factors. Second, we collected data from cities of China that can be extended to the whole of China and can also be extended by comparing e-bike adoption in different countries because the supply of E-bikes is very different and less in other countries. Third, we used snowball sampling, which can be improved by using different sampling and data collection techniques. Fourth, we focused on different factors that lead to the adoption of E-bikes, so our research model did not include any mediating variables. Future research can be improved by extending our study research model and by using one or two mediating variables. Fifth, because we used the TPB, this study encourages further research by using different theories, e.g., personality theory and social influence, as mediation factors.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AY: Conceptualization, writing-original draft, variable construction, and formal analysis. XH: Supervision, funding acquisition, writing—review, and editing. MA: Overall quality improvement, structure enhancement, writing—review and editing, and variable construction. RA: Writing review and editing. MKA: Writing review and editing. CI: Writing review and editing. AC: Writing review and editing. AA: Data curation, writing review and editing, and language improvement. IK: Data curation, writing review and editing, and language improvement.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2021.817107/full#supplementary-material

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Environmental Benefits From Carbon Tax in the Chinese Carbon Market: A Roadmap to Energy Efficiency in the Post-COVID-19 Era

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Because of China's global responsibilities to address climate change, the country has made a commitment to limiting the growth of future emissions using policy measures, such as funding mitigation research and regulating energy efficiency requirements directly. Extensions of these policies, such as the measures to improve energy efficiency, use of carbon taxes, and changes to the mix of electricity generation in the country, are also of interest to China. This article applied a computable general equilibrium (CGE) model to examine the effects of such energy efficiency and climate change policy options in the post-COVID-19 era in the China economy. The study findings show that even modest measures can have significant effects on emissions with marginal economic impacts, given the current level of development in the China electricity generation and transportation sectors. It is estimated that a 5 RMB per ton carbon tax will reduce emissions by 4.1% and GDP by 0.27%. Emissions drop by 8.2% and GDP drops by 0.54% when energy efficiency increases by 2% across the China economy, respectively. As a final result, a 5% shift away from burning coal would reduce emissions by 9.0%, while GDP would increase by 1.3%. It has been shown that even low carbon taxes can encourage a notable cleaner energy system.

Keywords: carbon market, carbon tax, energy efficiency, climate change, computable general equilibrium model

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INTRODUCTION

Steadily increasing carbon emissions are a major threat to environmental change (Yan et al., 2021), which represents both evolving countries' main ongoing anxiety for the developed economies (Akram et al., 2020; Irfan et al., 2020; Yumei et al., 2021). Economic development in developing countries requires thorough use of oil, which may lead to environmental degradation by extra waste and residues (Zhang M. et al., 2020; Elavarasan et al., 2021b; Khan et al., 2021; Wang et al., 2022). A large proportion of CO_2 emissions come from the use of fossil fuels (Elavarasan et al., 2021a; Irfan et al., 2021a; Dagar et al., 2021; Qiu et al., 2022), for example, coal, the key energy source of car industries, which is closely linked to the economic progress (Iqbal et al., 2019a). Electricity played the most significant role throughout the cycle of economic development. Capital investment flows have been the subject of research in Asian markets over the current years (Iqbal et al., 2021b; Shao et al., 2021). This issue can also be a cause for concern due to their high

uncertainty and deficit in the financial structures linked to the turbulent situation in emerging markets and the detrimental impact of financial crises in Latin America, Asia, and Russia (Iqbal et al., 2021a; Chien et al., 2021b; Mohsin et al., 2021).

In the mid-1990s, the latter became a vital category among the three groups of private capital flows, that is, direct foreign investment, portfolio investment, or bank loans. Its proportion of private venture capital in emerging market economies has increased substantially, suggesting a more conservative stance by foreign equity investors (Baloch et al., 2020; Yu et al., 2021; Rao et al., 2022). The assistance to storing energy is seen by governments across the world and in the United States as an essential component of grid decarbonization (Iqbal et al., 2019a; Yumei et al., 2021). Government corporations in China have approved legislation designed to improve the renewable energy mix using bulk storage that often defines the surrogacy target in terms of storage capacity (MW) or power (MWh) (Irfan et al., 2021a; Hao et al., 2021; Rauf et al., 2021; Yang et al., 2021). The MEP has, along with the NDRC, adopted two process-oriented policy measures since 2014 in order to eliminate pollution causing pollutants from coal-fired power plants: 1) a regulation on volatilization (Zhao et al., 2020a), sweat reduction, and dust collection equipment, and 2) an electrical quality advantage for units that have the environmental appliance (Zhao et al., 2020b). It would make it possible for the former to introduce by raising the cost obstacles to their implementation (Li Z. et al., 2021). The required instrument suggests that the government is ready for standardized environmental equipment to be used by coal-fired power plants, but the reliability of implementation was not as high as anticipated due to the high operation and maintenance costs.

As a provisional instrument for providing economic incentives, the electricity pricing premium works. Both instruments are a mix of "carrots and sticks," but as the climate is widespread among potential carbon-fired power plants, price premium opportunities may appear excessive and be slowly reduced in order to increase the cost-effectiveness in general (Hou and Xu, 2020; Wu B. et al., 2021; Irfan et al., 2021b). Environmental tax can enable the electricity price premium to be implemented effectively by providing additional incentives to install environmental equipment for power stations (Wang L.-W. et al., 2019; Yam et al., 2019). Increased renewable energy (wind and solar) has reduced savings (Irfan et al., 2019a, 2019b; Iqbal et al., 2019b; Nuvvula et al., 2022), with overall lower prices and thus low cutting levels leading to a reduction in financial benefits both for centralized and distributed cases (Li et al., 2018; Wang L.-W. et al., 2019). Improved thermal storage efficiency also contributed to increased savings on the network as a whole, although they were smaller on the consolidated case per unit of energy (Majumder et al., 2019; Zhang J. et al., 2020). The errors in the thermal environment may be triggered. Improved electric car efficiency contributes to lower savings for the dispersed case, but a modest improvement for core cases. Greatly increased CO_2 emissions contribute to higher commodity costs under both the concentrated and localized management systems, thereby offering a marginal gain for production (Fang et al., 2021; Islam et al., 2021). Greater demand indicates that the model is limited since capacity generation for specific scenarios is established, thereby increasing the demand (Rivera, 2017; Dolter and Rivers, 2018). The model is not significant. Reducing demand in both instances significantly reduced savings, while the effect was much stronger for distributed cases, and that is due to the fact that consumers flatten irrespective of the system; when the price differentials are not sufficiently large, they lose out because of operating stock losses; that is, additional energy needed for storage operations is more costly than the ripples (Fahria et al., 2021). Increases in gas and coal fuel prices lead to increased cash reserves both in centralized and distributed situations, while centralized modification is reduced. One exception is the distributed gas increase scenario case that can be stated by consumer herding.

Previous studies suggest that system emissions tend to increase profit or value trying to maximize income (Yi et al., 2018; Asbahi et al., 2019; Wang S. et al., 2019). Nevertheless, shifts in the carbon dioxide process operating approaches and practices have not been studied (Ahmad et al., 2021; Ali et al., 2021; Li Y. et al., 2021; Jinru et al., 2021; Tanveer et al., 2021; Elavarasan et al., 2022). We address this idea directly by assuming that the well-established decreases in carbon emissions associated with generating income and reducing pollution might be attenuated by alternative operating strategies aimed at reducing emissions. To check that, a computable general equilibrium (CGE) model is used to maximize the trade-offs among the emissions, energy usage, and pollution intensity by calculating the carbon tax to fund energy efficiency and climate change mitigation programs.

Carbon tax and energy efficiency measures are being compared to show how they affect the Chinese industrial sector, as well as CO_2 emissions reduction. Thus, this work contributes to the discussion on how to design policies and strategies that can be implemented in the fields of energy, environment, and sustainability.

This article is organized as follows: *Literature Review* outlines the methodology, *Method and Data* summarizes the findings and sparks discussion, and *Results and Discussion* summarizes the implications for policy-makers.

LITERATURE REVIEW

Carbon taxes are the subject of the earliest scholarly investigation in this area. Standard taxation and collection methods are at the heart of the carbon tax policy design as a useful resource management and environmental tool (Liu et al., 2020). Scholars have devised the carbon tax user cost theory in an effort to improve the framework for theoretical analysis of carbon taxes (Ding et al., 2020). Many studies have shown that a fair tax on resources not only ensures that consumers pay their fair share of the costs but also has the potential to improve the environmental impact of resource use (Liu Z. et al., 2021). According to Boadway and Keen, 2010, the user cost of resources in South Africa was calculated, and a discussion was held about the country's resource tax rate. Even though resource taxes can reduce CO_2 emissions and improve resource utilization efficiency, economic growth suffers as a result (Zhou et al., 2018).

In addition, the effectiveness of China's carbon regulation is being examined, as are the country's carbon intensity, scale, and performance (Chen et al., 2020; Wu H. et al., 2021). SOEs' performance will suffer more if the central government sets a higher carbon intensity reduction target than they already have (Liu et al., 2018). The output size and carbon intensity are the two most important determinants of changes in CO_2 emissions, and the mining industry as a whole should put forth more effort to meet the peak target.

Since the 1980s, a lot of scholars have studied carbon taxes (Lin and Jia, 2018; Fremstad and Paul, 2019; Hájek et al., 2019). According to academics, the green and blue dividends of carbon taxes are mutually reinforcing (Carattini et al., 2019; Hagmann et al., 2019; Razzaq et al., 2021). A carbon tax's revenue can be used to offset other business taxes, improving the economy and spurring more employment and investment (Metcalf and Weisbach, 2009). In addition to this, it can improve environmental quality (the "green dividend"). Energy conservation and efficiency can be improved by carbon taxes based on these findings (Ojha et al., 2020). Reduced CO_2 emissions can be achieved through the use of carbon taxes (Zhu et al., 2020). When the level of GDP per capita is high (Yu, 2020), environmental taxes may have a positive impact on economic growth (An and Zhai, 2020). Taxes on carbon have been shown to have a negative impact on energy production (Cheng et al., 2021). Reducing pollution through a fee on polluting goods and services (Rathore and Jakhar, 2021), increasing capital (Sabine et al., 2020), and decreasing pollution using a premium or subsidy are all possible outcomes of a pollution tax (Wang et al., 2021). However, because of the benefits carbon taxes provide, Tiwari et al., 2021 believe that the negative impact on GDP caused by carbon taxes is acceptable. Similar and wide-ranging studies have been conducted in the United Kingdom (Jiang and Yang, 2021), the United States of America (Carroll and Stevens, 2021), China (Ma et al., 2020), and India (Liu Y. et al., 2021).

In resource and environmental policy analysis, the CGE model is widely used (Chen et al., 2020; Mehleb et al., 2021; Sun and Yang, 2021). As a result of taxation, a variety of macroeconomic variables are affected (Li and Yao, 2020). Many academics build national-level CGE models to find the best resource tax rate (King et al., 2019; Li L. et al., 2021; McAusland, 2021). China's dynamic macro CGE model, for example, was developed by Liu and Hu (2015), and it investigated the effect of carbon tax on the rural economy of China. Liu et al. (2018) developed China's dynamic CGE model to examine the macroeconomic and resource environment's impact on resource tax policies. A consequence of this is that some researchers are now concentrating more on local issues rather than more global ones. Researchers in China's Guangdong Province have developed an energy computable general equilibrium (CGE) model, and found that a carbon tax is more effective at cutting emissions and saving energy than a similar consumption tax. According to Hu et al., 2021, a carbon tax in Shanxi Province could affect employment by using the dynamic CGE model.

Comparative analyses of carbon taxes can be seen from the earlier research review, but few of these previous comparisons are available (Denstadli and Veisten, 2020; Runst and Thonipara, 2020; Fu et al., 2021). The use of energy, emissions of carbon dioxide (Luo et al., 2021), and macroeconomic effects have all been the subject of numerous studies (Li et al., 2020; Tovar Reaños, 2020); however, only a few studies have examined the environmental impact of carbon taxes. Using data from China's input–output table and the computable general equilibrium (CGE) model, we examined the effects on energy efficiency and environmental protection of increasing carbon taxes. China's carbon tax reforms can be aided by this study's findings, and it can also serve as a model for other countries.

METHOD AND DATA

It is easy to understand how economic factors act and react when using the general equilibrium model, which provides a simplified depiction of the economy (Bourgeois et al., 2021). For the general equilibrium model, prices and values are simultaneously adjusted to establish the equilibrium and optimization conditions, unlike traditional macro-level models such as linear programming models or input–output models (i.e., the income equilibrium condition, market clearing condition, and zero-profit condition) (Nie et al., 2020). In other words, prices and values in general equilibrium models are both endogenous variables, unlike in linear programming and input–output models (Boonmee et al., 2021). In other words, finding the endogenous variables was the primary goal of solving the general equilibrium model (i.e., equilibrium prices, values, and incomes) (Chien et al., 2021a). General equilibrium models, unlike econometric models, require data and fewer statistics, and use data from a reference year instead of a wide range of data and periodic statistics. Other econometric studies' statistics and data on elasticity can be used. According to the calibration method, the general equilibrium model's parameters are derived from the data and statistics of the reference year.

Model Selection

This article applied a general equilibrium model that incorporates a carbon tax policy module in order to evaluate the economic effects of carbon tax policies, emission reduction, and energy-saving (Dumortier and Elobeid, 2021). Assuming the market factor flow and clearing, the model is constructed. In order to improve the standard CGE model, we make the following modifications: 1) the factor accounted energy components are divided into subgroups. The CGE model does not break down the energy elements. It was decided to separate energy from fuel oil and natural gas for this article based on China Energy Statistical Yearbook (2018) and data from those sources. The energy components were analyzed separately from the fuel oil and natural gas components. Energy is supplied by the Cobb–Douglas function. Subdividing the energy sector is necessary for tracking changes in energy consumption and simulating the effects of carbon tax policies. The mining industry is divided up in the production module. Input–output data from China cover the coal and oil and gas industries, as well as the mining and processing industries for ferrous, non-ferrous,

TABLE 1 | China macro-SAM 2017 (billion RMB).

Receipts	Activities	Labor	Commodities	Households	Capital	Tax	Enterprises	Savings-investment	Government
Activities		230397							
Labor	42,975								
Commodities	146320				32,683		12,622		37,283
Households			42,975	3,368			6,943		
Capital	31,413								
Tax	9,687				1,220	3,275			
Enterprises				28,045					
Savings-investment					19,385	24,769	5,382		
Government								14,183	

and non-metallic metals, as well as the auxiliary mining activities (2017). In China, the tax rates on various resources vary. Consequently, the mining industry was broken down to simulate China's carbon tax policy. In order to assess the environmental impact of various tax policies, CO_2 and air pollutant emissions were included in the output module.

This article uses neoclassical closures. Commodity markets were cleaned up. At a given price and exchange rate, the quantity of goods becomes endogenous imports, and exports are quantitatively unlimited. The general equilibrium condition is satisfied as long as all domestic goods are available.

$$Q_s = \sum_a QINT_{ca} + \sum_h QINV_c + Q_{ch} + QG_c, \tag{1}$$

where Q_s indicates the commodity supply in the Chinese domestic market, INV_c is the investment demand for the commodity, and Q_{cd} is the consumer demand of commodity c of household h.

$$GDP = \sum_c \sum_h QH_{c,h} + QINV_c + \sum_c QG_c + \sum_c (QE_c - QM_c). \tag{2}$$

Data

The social accounting matrix (SAM) is the base data for the CGE model's calculations. There are two rows and two columns in a SAM for each account. Each cell displays the transfer of funds from the column's account to the row's account. Consequently, the income and expenditures of an account are displayed in its column and its row, respectively. The sum of each SAM account's revenue and expenditure is equal to its total revenue (row total and column total).

All of the economic system's production modules are described in detail by SAM. The factor input is where the household and industrial sectors get their income in a social accounting matrix. Consumption and production are linked in an economic cycle because of the link between income and demand for consumption. The SAM was constructed using data from the "China's input–output table" (2017), China Tax Yearbook (2018), China Statistical Yearbook (2019), Energy Statistical Yearbook of China (2018), China Environmental Statistical Yearbook (2018), and the National Bureau of Statistics. The 2017 China macro-SAM is shown in **Table 1**.

TABLE 2 | Coefficients of carbon emission from various energy sources.

Energy	Coefficient of coal	Coefficient of CO_2 emission
Coal	0.77	2.04
Coke	1.04	3.06
Crude oil	1.53	3.24
Gasoline	1.58	3.14
Kerosene	1.58	3.24
Diesel oil	1.56	3.32
Fuel oil	1.53	3.40
Natural gas	1.42	2.31

Research questions necessitate the decomposition or aggregation of data when compiling a social account matrix. Because of China's current energy, the mining industry status, and the available data, the production sector was divided into 35 sectors. Agriculture is the main economic activity. Farming, forestry, animal husbandry, fishery and water conservancy; coal mining and dressing; petroleum and natural gas extraction; ferrous metals' mining and dressing; non-ferrous metals' mining and dressing; non-metal minerals' mining and dressing; other minerals' mining and dressing; logging and transport of wood and bamboo; food production; beverage production; tobacco processing; textile industry; leather, furs, down, and related products; petroleum processing and coking; raw chemical materials and chemical products; medical and pharmaceutical products; chemical fiber rubber products; plastic products; non-metal mineral products; smelting and pressing of ferrous metals; metal products ordinary machinery; equipment for special purpose; transportation equipment; electric equipment and machinery; electronic and telecommunications equipment; instruments, meters, and cultural and office machinery; other manufacturing industry; scrap and waste; electric power, steam, and hot water production and supply; gas production and supply; tap water production and supply; construction; transport, storage, postal, and telecommunication services were all included in the secondary industry's categories. Transportation, wholesale, retail, and other tertiary industries comprised the tertiary industry.

The air emission module's relevant parameters needed to be set up, and that was a major focus of this article. We used the following methods: analyzing and contrasting the CO_2 emission

TABLE 3 | Simulation scenarios' setting.

Carbon tax policy	Tax
Case 1	5 yuan/ton of CO_2
Case 2	10 yuan/ton of CO_2
Case 3	40 yuan/ton of CO_2

parameters of various energy sources. **Table 2** shows the CO_2 emission coefficients of various energy sources based on data from Zhou and Hong (2018), China's Energy Statistical Yearbook, and the 2006 IPCC national greenhouse gas inventory guidelines.

$$En_{CO_2} = \sum_i E_i \times S_i \times Ef_i. \tag{3}$$

where En_{CO_2} energy consumption is the sum of all the CO_2 emissions that result from that consumption, E_i indicates the energy consumption, S_i represents the standard coal conversion coefficient for a variety of energy sources; and Ef_i represents the emission rate of CO_2.

RESULTS AND DISCUSSION

China does not have a carbon tax at this time. Carbon taxes have been advocated by a number of academics. There are more reasonable arguments in favor of such a tax based on the findings of the results. Although a 40 yuan/ton CO_2 carbon tax on production sector energy consumption is assumed, there is no carbon tax on residential sector energy emissions. It was decided to gradually raise the carbon tax because there is a widespread belief that high tax rates harm the economy (Li G. et al., 2021). All three scenarios (scenario 1, scenario 2, and scenario 3) were run in order to see how the carbon tax would affect the economy and the economy's ability to absorb CO_2 emissions. A carbon tax is a factor that reduces energy use and, as a result, CO_2 and other emissions from air pollutants. Taxes on carbon also increase the tax burden on businesses, which is detrimental to business and household income gains as well as to economic growth in general. For businesses, household income, and national economic growth, this is not a good thing. **Table 3** displays the finalized simulation scenarios.

Carbon Tax Effect on Energy Efficiency

In the first year of implementation, by imposing a carbon tax, China's carbon emissions are reduced by 1.1%, and the cumulative reduction is 9.8%. **Table 4** shows that the decrease in carbon emissions caused by the use of coal is responsible for a large portion of the decline (8.2%). Because coal is the primary source of energy and most carbon-intensive fuel in China, this is expected. Liquefied petroleum gas (LPG), gasoline, and diesel oil will all contribute to a 2.3% reduction in greenhouse gas emissions. Regardless of the carbon tax, natural gas-related carbon emissions have increased by 5%. Natural gas and other carbon-free power generation technologies are replacing coal-fired plants in the electricity industry as a result.

Macroeconomic Effects

However, environmental benefits come at a price, as GDP shrinks and household income drops as a result of these changes. There will be a 0.1 and 0.6% decrease in real GDP growth in 2015 and 2020, respectively. **Table 5** shows how much each component of GDP contributes to the overall change in GDP. It demonstrates that falling of total consumption, investment, and government spending have all contributed to a decline in real GDP over time. The total consumption and investment will both shrink by 0.6%, while government spending will fall by 0.1%. By 0.2%, exports have grown, while imports have decreased by 0.4%. **Table 6** depicts the changes in price indices across the entire economy. Despite a cumulative drop in the CPI of 0.1%, aggregate real consumption will shrink by 0.6%. Consumption declines are linked to a 1.2% real income reduction for all households. The nominal factor returns are decreasing, which in turn reduces real household income and nominal household income, as shown at the bottom of **Table 5**. The combination of falling income and rising unemployment has a negative impact on household spending.

Though energy prices have risen due to the carbon tax, the GDP price deflator has decreased (**Table 5**). Higher energy prices

TABLE 4 | Carbon emissions from different sources of energy.

	Energy efficiency			Energy efficiency + energy mix		
	5 yuan/ton of CO_2	10 yuan/ton of CO_2	40 yuan/ton of CO_2	5 yuan/ton of CO_2	10 yuan/ton of CO_2	40 yuan/ton of CO_2
	% change	% change	% change	% change	% change	% change
Coal	5.05	7.9	9.15	−0.95	−2.81	−5.38
Coke	−0.09	−0.19	-0.28	−0.72	−2.13	−4.14
Crude oil	−0.11	−0.23	−0.35	−0.76	−2.24	−4.34
Gasoline	−0.14	−0.29	−0.44	−0.27	−0.83	−1.64
Kerosene	−0.15	−0.33	−0.52	−0.55	−1.61	−3.16
Diesel oil	−0.17	−0.34	−0.52	−0.34	−1.00	−1.99
Fuel oil	−0.12	−0.27	−0.39	−0.92	−2.71	−5.19
Natural gas	−0.17	−0.34	-0.51	−0.39	−1.16	−2.29
Total CO_2 emissions	−4.1	−5.91	-6.14	−4.9	−14.49	−28.16

TABLE 5 | Macroeconomic effects.

Variables		Energy efficiency			Energy efficiency + electricity mix		
		5 yuan/ton of CO_2	10 yuan/ton of CO_2	40 yuan/ton of CO_2	5 yuan/ton of CO_2	10 yuan/ton of CO_2	40 yuan/ton of CO_2
	Base value (billion RMB)	% Change	% Change	% Change	% Change	% Change	% Change
Consumption	32,779	−0.26	−0.28	−0.31	−0.01	−0.016	−0.03
GDP	84,320	−0.27	−0.45	−0.55	−0.11	-−0.32	−1.02
Imports	15,270	−0.35	−0.46	−0.57	−0.11	−0.32	−1.03
Exports	16,759	−0.59	−0.96	−1.32	−0.34	−1.01	−2.19
Labor force	43,101	−0.037	−0.049	−0.061	−0.06	−0.17	−0.56
stocks	2,562	0.26	0.28	−0.29	−0.02	−0.06	−0.21
Government spendings	45,326	−0.43	−0.63	−0.82	−0.18	−0.55	−1.76
Secondary industry value-added	36,431	−0.25	−0.26	−0.29	−0.02	−0.05	−0.16

TABLE 6 | Effects on industrial-level output.

	Energy efficiency			Energy efficiency + electricity mix		
	5 yuan/ton of CO_2	10 yuan/ton of CO_2	40 yuan/ton of CO_2	5 yuan/ton of CO_2	10 yuan/ton of CO_2	40 yuan/ton of CO_2
Farming, forestry, animal husbandry, fishery, and water conservancy	−0.16	−0.17	−0.18	−0.11	−0.12	−0.12
Coal mining and dressing	−0.14	−0.15	−0.15	-0.10	−0.10	−0.11
Petroleum and natural gas extraction	−5.52	−7.73	−8.83	−0.08	−0.10	−0.11
Ferrous metals' mining and dressing	−0.27	−0.28	−0.30	−0.19	−0.22	−0.25
Non-ferrous metals' mining and dressing	−0.60	−0.63	-0.66	−0.42	−0.46	−0.51
Non-metal minerals' mining and dressing	−0.40	−0.42	-0.44	−0.28	−0.31	−0.34
Other minerals' mining and dressing	1.87	1.96	2.06	−0.61	−0.67	−0.74
Logging and transport of wood and bamboo	−0.70	−0.74	−0.77	−0.49	−0.54	−0.59
Food production	1.70	1.90	2.13	−0.49	−0.52	−0.55
Beverage production	−0.17	−0.18	−0.19	−0.13	−0.13	−0.14
Tobacco processing	−0.13	−0.14	−0.14	−0.09	−0.10	−0.10
Textile Industry	−0.60	-0.63	−0.66	−0.42	−0.44	−0.47
Leather, furs, down, and related products	−0.23	−0.23	−0.24	−0.16	−0.17	−0.18
Petroleum processing and coking	−0.36	−0.37	−0.37	−0.25	−0.27	−0.28
Raw chemical materials and chemical products	−0.51	−0.57	-0.64	-0.36	-0.38	-0.40
Medical and pharmaceutical products	2.34	2.62	2.94	−0.24	−0.25	−0.27
Chemical fiber	2.60	2.91	3.26	−0.42	−0.46	−0.50
Rubber products	−0.15	−0.17	−0.19	−0.11	−0.11	−0.12
Plastic products	−0.30	−0.34	−0.38	−0.21	−0.23	−0.25
Non-metal mineral products	−0.60	−0.70	−0.82	−0.42	−0.46	−0.50
Smelting and pressing of ferrous metals	1.90	2.22	2.60	−0.63	−0.75	−0.89
Metal products	2.60	3.04	3.56	−0.42	−0.46	−0.50
Ordinary machinery	1.50	1.76	2.05	−0.35	−0.39	−0.42
Equipment for special purpose	2.60	3.04	3.56	−0.42	−0.50	−0.59
Transportation equipment	3.00	3.51	4.11	−0.21	−0.25	−0.30
Electric equipment and machinery	1.80	1.87	1.95	−0.56	−0.67	−0.79
Electronic and telecommunications equipment	−0.80	−0.83	−0.87	−0.56	−0.62	−0.68
Instruments, meters, and cultural and office machinery	1.20	1.25	1.30	−0.14	−0.15	−0.17
Other manufacturing industry	−0.70	−0.80	−0.91	−0.49	−0.54	−0.59
Scrap and waste	1.20	1.25	1.30	−0.14	−0.15	−0.17
Electric power, and steam and hot water production and Supply	−0.70	−0.73	−0.76	−0.49	−0.54	−0.59
Gas production and supply	2.40	2.50	2.60	−0.28	−0.31	−0.34
Tap water production and supply	−0.20	−0.21	−0.22	−0.62	−0.69	−0.75
Construction	−0.45	−0.47	−0.49	−0.53	−0.58	−0.64
Transport, storage, and postal and telecommunications services	−0.50	−0.52	−0.54	−0.35	−0.39	−0.42

have a smaller effect on output prices than lower labor and capital costs, which is the primary reason for this. Companies cut back on production as a result of rising energy costs. Due to the fact that the primary factor demand is linked to output levels, companies reduce their employment, resulting in lower wages for the entire economy. Lower output, in turn, means lower

profitability, and lower profitability means a lower return on capital. As a result of the lower cost of capital, demand for investment goods and the production are reduced, resulting in an overall decrease in investment.

Table 5 shows the impact of the general level of prices and falling output prices on the export price index. Because of this, trade terms deteriorate and the real exchange rate depreciates, resulting in lower prices. Both of these factors make China's exports more competitive in the global market, resulting in an overall increase in exports. Exports of semiconductors, which account for about 80% of total exports, are particularly strong. This is why the semiconductor industry is expanding its output (**Table 6**). As a result of the depreciation of the real exchange rate, the demand for imports has decreased (Dorsey-Palmateer and Niu, 2020).

Most industries see their output shrink as a result of the carbon tax (**Table 5**). This is especially true for those companies, whose demand for carbon-emitting fuels decreases. Coal is the industry that has had a hardest hit. Its output drops by 0.5% in the first year and by 9.7% as a result of the carbon tax. Carbon-emitting fuel consumption will fall by 2.3% as the economy reduces its use of fossil fuels. Also, the "crude oil and natural gas extraction" industry is expected to see a 1.7% decrease in production output. Non-ferrous metals' mining and the dressing industry have the highest output decline among non-energy-producing industries. In part, this is due to the industry's reliance on carbon-emitting inputs, such as coal-intensive cement manufacturing.

That is exactly what we would expect from this. A total of 22.6% of coal-fired electricity generation's output will be reduced due to the carbon tax, which has the most significant effect on this industry. It also encourages the use of oil and natural gas as well as carbon-free sources of energy in the electricity sector such as hydropower, geothermal power, and renewables, which are less carbon-intensive than coal. Energy output from hydrothermal, geothermal, and renewable sources has increased by 20, 14.5, and 14.8% over the past few years. Additionally, electricity generated from natural gas and less carbon-intensive oil is up by 3 and 7.9%, respectively. Natural gas accounts for 28% of the electricity generated, while oil accounts for only 11.5%. As a result, the increase in electricity output from natural gas production is greater than the increase in oil production.

Discussion

For economists, policy scientists, and policy-makers who want to put a price on carbon, the issue of optimal carbon pricing mechanisms has long been hotly debated. Some researchers argue that a direct carbon tax was imposed, and others advocated the introduction of cap-and-trade. One-third of the group argued that both policies were identical (i.e., that a particular cap-and-trade system can imitate a carbon tax, and *vice versa*). Accordingly, an in-depth examination of the green economy's growth determinants is considered important. Public spending changes are viewed as a key indicator for this study. Government spending as a percentage of GDP ranges from 20 to 45%. (Aly et al., 2017). Over the last decades, a number of countries across the globe have achieved healthy economic growth. However, such economic achievements made those countries the higher emitters of CO_2.

Based on the results of a simulation, we can see what happens to the entire economy. The findings showed that non-energy sectors and electricity generation efficiency are both improved by 2%. The efficiency gains will result in a reduction in total carbon emissions of 4.1% below 5 Yuan per ton CO_2 emissions. There is a total of 5.05% cumulative reduction in carbon emissions in the coal-burning scenario and 0.95% in the diesel, fuel oil, natural gas, and gasoline scenarios. There has been a slight increase in the emissions of LPG and other petroleum products, but greater reduction in emissions from other more carbon-intensive fuels has offset these emissions. Unlike a carbon tax, natural gas emissions fall in this scenario, whereas they rise in the latter. Real GDP increased by 0.3% compared to the baseline, and it is expected to increase by another 1.9%. Investment and consumption account for 1.7% of the GDP growth in total, making them the two main components. Exports are declining and imports are rising, which has resulted in lower real GDP growth. Wages rise in response to an increase in the supply of labor, which in turn leads to an increase in output. As output increases, rents (for both capital and land) rise, which in turn boosts industry profitability. As a result of this increased profitability, investment goods production and demand will rise by 0.8%. The export price index rises as the cost of local production rises. Increasing export prices result in a real exchange rate of 0.59% and a trade term improvement of 0.46%. Due to these two factors, cumulative exports will be 0.73% lower, imports will rise by 0.23% as the real exchange rate rises, and the cost of imported goods decreases. The well-being of families can be improved through the implementation of efficiency measures. The higher primary factor returns do help them, and it is true. Real GDP increased by 0.32% compared to the baseline, and it is expected to increase by another 1.6%. Investment and consumption account for 0.64% of the GDP growth in total, making them the two main components. Exports are declining and imports are rising, which has resulted in lower real GDP growth.

As a result of greater energy efficiency, most industries have seen an increase in output (**Table 5**). Energy-producing industries, whose output decreases as a result of increased energy efficiency, are the exception here. Oil-fired power generation will increase output by 0.2%, while renewable power generation will increase output by 3.3%, with the electricity sector expected to see the most growth. The well-being of families can be improved by implementing efficiency measures. Higher primary factor returns do help them. The final policy simulation examines an alternative electricity generation mix policy following efficiency gains in the previous simulation. Over the next 3 years, coal will be phased out in favor of renewable energy. For the most part, there are few notable differences between this and the energy efficiency simulation. Total carbon emissions will be reduced by 17.32%, which is 3.15% points more than if only efficiency improvements had been implemented. Because it reduces emissions by 8.1%, coal is to blame for the discrepancy. Electricity generated from renewable sources will rise by 12.21%, while output from coal-fired power

plants will fall by 10.18%. The output of petroleum and natural gas extraction increased by 5.52% as a result of lower natural gas prices. In comparison to the previous scenario, an identical shift in the output of alternative energy sources can be observed.

CONCLUSION AND POLICY IMPLICATION

Although the Chinese government's emissions targets are clearly ambitious, there must be some doubt as to whether it has sufficient policy instruments under its direct control to encourage businesses and households to act in a way that ensures these targets are met. This study was conducted to fill the void left by the lack of previous research on the impact of carbon taxes on China's energy, environmental, and economic sectors. The study findings show that the effects of a carbon tax on China's economy have been examined, and the results show that the country's energy efficiency will be improved, and also energy consumption and carbon dioxide emissions will be reduced under three scenarios of taxation.

Policy Implication

According to the findings of this study.

1. Carbon dioxide emissions are slightly more affected by taxation without compensation than when households receive a lump sum payment for their taxes.
2. It has been found that if a government has no budget deficit, a tax based on the carbon content of each energy carrier can better align energy pricing with the government's goal of reducing greenhouse gas (GHG) emissions.
3. Carbon taxation with revenue redistribution is therefore an effective policy for increasing social well-being and reducing emissions, even if external effects due to improved environmental quality are not taken into account.
4. For a 100% reduction in pollutant emissions, a carbon tax of 50% would be required, according to model simulations. Emissions can be reduced by as much as 50% under suggested scenarios if taxes are imposed, which is the minimum reduction.
5. Carbon taxes should be enacted regardless of the availability of a suitable basis for calculating energy prices, given the positive effects on welfare, unemployment, energy savings, and reductions in pollutant emissions. This is true as long as the labor tax is decreased, and the total tax revenues of the government remain constant.
6. The policy of carbon tax is only recommended insofar as it reduces other taxes and revenues, such as income tax, employer-provided unemployment insurance, and social security benefits. Labor taxes can be negative in order to keep total tax revenues the same.

Research Limitation and Future Direction

Additional production inputs (instead of energy labor and capital), markets, and production sectors can be added to the selected model in future works. In this case, a more flexible production function can be an important consideration, such as translog instead of CGE. Competition and constraints, as well as uncompetitive conditions, are the starting points for the selection of equations in most general equilibrium studies. It has been performed in a similar way in the current study with Iran's economy as the only uncompetitive condition taken into account. Other uncompetitive economic conditions can be incorporated into the general equilibrium model in future studies.

A carbon tax that applies to every sector of the economy, fossil fuels of all kinds, and all regions of the country cannot achieve the goal of implementing a carbon tax policy that internalizes the external costs of emissions. As a result, this study's 30% tax rate does not imply that the earlier considerations are not important. Different tax rates can be compared in future studies, including household and production sectors, to see how they affect the economy and environment.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Households' Perception and Environmentally Friendly Technology Adoption: Implications for Energy Efficiency

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Since employing environmentally friendly technologies (EFTs) is a complicated and difficult process that is affected by multiple factors, researchers are encouraged to explore those influence factors. This research aims to estimate the households' perception factors affecting the adoption intentions of EFTs. Based on a questionnaire survey from 782 Pakistani households, a structural equation modeling strategy yields empirical results. The main findings are: firstly, the drivers of adoption intention of EFTs include technological awareness, perceived environmental importance, perceived behavioral control, and perceived benefits. Secondly, significant barriers to the adoption intention of EFTs involve the perceived cost of EFTs and the perceived risk-averse behavior of households. Thirdly, among all factors, perceived environmental importance reveals the most substantial contribution, whereas perceived risk-averse behavior shows the least contribution to the adoption intention of EFTs. Finally, given these results, strengthening the financial benefits, controlling the roaring cost of EFTs, and the provision of rebates and subsidization are suggested to upscale the adoption intention of EFTs by the households.

Keywords: environmentally friendly technologies, household perception, sustainable environment, structural equation modeling, Pakistan

INTRODUCTION

Fossil fuels consumption for power production is a compelling factor that promotes greenhouse gas (GHG) emissions (Inglesi-Lotz and Ajmi, 2021; Ahmad and Wu, 2022). The most optimistic solutions for sustainable development and emission reduction involve switching from conventional technologies to environmentally friendly technologies (EFTs) (Adedoyin et al., 2021; Dogan et al., 2021; Irfan and Ahmad, 2021). Adopting such measures could prevent up to 30% of the GHGs in various areas like the manufacturing and energy sectors (Jabeen et al., 2020; Ahmad et al., 2021c). However, due to the existence of a gap in energy efficiency, the implementation of technology as well as technical solutions might not be enough to decrease power consumption (Ozcan and Ozturk, 2019; Ahmad et al., 2021d; Irfan and Ahmad, 2022). Pakistan's industrial areas are a platform for various products, including steel, petrochemicals, aircraft, computers, and many other consumer

products. In this regard, Pakistan's industrial sectors contribute around 20% to GDP, decreasing in current years. As per the energy background of Pakistan, the manufacturing industry, shipping vehicles, and public mobility involve around 60% of the total energy demand in the industrial sector (Irfan et al., 2020; Rehman et al., 2021a). Subsequently, there are numerous prospects for adopting and utilizing EFTs to lessen ecological effects and decrease manufacturing costs, though corporations and customers did not yet consider all varieties of gainful opportunities to be applied in power supply and consumption (Shah et al., 2020; Satrovic et al., 2021). The present era demands shifting the focus on the adoption and development of EFTs to alleviate environmental degradation and climatic adversities.

Being a growing economy, Pakistan needs more than enough energy goods to deal with the country's energy escalating demands. Despite having huge reserves and energy generation capabilities, Pakistan's economy is incapable of meeting its main energy requirements and has suffered serious energy catastrophes (Ahmad et al., 2021b; Rehman et al., 2021b). As of 2018, a notorious power shortage of approximately 9000 MW has been recorded in the country, causing a power blackout of up to 13–15 h a day in the rural settings and 6–8 h a day in the urban regions. In this scenario, the development of EFTs is anticipated to position the required solution. Despite having an abundant potential in renewables, the utilization of EFTs is yet far behind its optimum level in the country (Aized et al., 2018). Given the foretold story, the adoption of EFTs may assist in times of load shedding in the country. The incapacity to ensure the requisite electricity supply creates an obstacle in a nation's economic development and has tucked its people's daily lives. The dwindling supply of electrical energy has contributed greatly to frustration and unpredictable circumstances for both household consumers and businesses, thus forcing them to switch to alternative solutions (Rehman et al., 2020; Solangi et al., 2020). This continuous hiding and searching for conventional electricity has led to the of EFTs. It is further argued that Pakistan is lucky to have a large potential for developing EFTs in terms of renewables, which could help to curb import spending and reduce emissions (Fatima et al., 2019), leading to sustainable futuristic solutions.

The mainstream scholars promoting environmental technologies investigated and emphasized the understanding of how users make decisions regarding the purchase of EFTs when those decisions require a trade-off between different costs and benefits associated with those technologies (Hartmann and Apaolaza-Ibáñez, 2012; Rehman et al., 2021c). In this way, the existing literature highlights the significant aspects responsible for revealing the desirability of those technologies. Concerning this, Lam et al. (2016) conducted a study in Hong Kong considering 180 consumers using Bonaqua (a water provider brand). Their outcomes showed that consumer satisfaction mediated the relationship between consumer perception about new technologies and repurchase intentions. Similarly, Wang et al. (2019) presented this concept from the perspective of consumers' perception about the profitability of the products (i.e., perceived benefits), presenting consumers' general evaluation based on the net profit of a product or a service. However, they failed to incorporate several vital aspects of household perception. On the contrary, a positive effect of environmentally friendly nature, greenness, and the perceived quality of innovative technologies on consumer trust and adoption process of those technologies (Chen et al., 2015; Ahmad et al., 2019). Gilly (1992) described the perceived benefits associated with the functional value of EFTs. Gilly viewed the perceived usefulness obtained from the substitute's ability to operate and physical working capacity. Some studies also investigated and revealed that the social values considerably encouraged consumers to make an investment in ecological endeavors (He and Veronesi, 2017). Jacksohn et al. (2019) revealed that while purchasing a product, emotions and feelings are influential as compared to the operational benefits that could be gained by using a product. Rebates and other inducements encourage adopters of EFTs to make an investment in the purchase of those technologies by reducing their risk-averse behavior (Carfora et al., 2018). Kapoor and Dwivedi (2020) investigated the factors affecting consumers' intention to adopt solar technology in India and found that perceived benefit encouraged intentions to adopt the technology. Finally (Jabeen et al., 2021a), considered perceived cost and benefits to be the influential factors of green technology adoption in Pakistan. However, their model did not consider the vital aspects of technological awareness, perceived environmental importance, and perceived risk-averse behavior of households.

The past studies lacked in several directions addressed by our study. To date, mainstream work has primarily discussed the adoption of various EFTs such as green technologies, solar power systems, biogas technology, energy efficiency technologies, and renewable energy technologies in general. The studies addressing the household perception regarding the adoption of those technologies are scarce. Additionally, the past studies left some crucial factors unaddressed. For instance, technological awareness may play a critical role in the adoption process since without understanding and perceiving an innovative technology, the adoption of EFTs would be sluggish. Moreover, the perceived environmental importance is a key factor in EFT adoption since if the households value their surrounding natural environment, they would perceive the necessity to adopt EFTs. Additionally, consumers are risk-averse to investing in innovative products. Therefore, addressing their risk-aversion could enhance EFT adoption intention. From the theoretical front, no research has been known to incorporate the perception factors into intention theory, such as the theory of planned behavior (TPB). This is critical since what consumers perceive shapes their intentions to perform some action, such as EFT adoption.

This research defines and analyzes the perceived aspects of households' adoption intention of EFTs with a specific emphasis on 1) technological awareness (TAW), 2) perceived environmental importance (PEI), and 3) perceived risk-averse behavior (PRAB). Unlike the previous studies, the recent work considers these variables in the form of EFT market consideration by addressing the adoption intentions of households. This study developed a comprehensive questionnaire and surveyed ten EFT hot destination cities of Pakistan. The data collected from 782

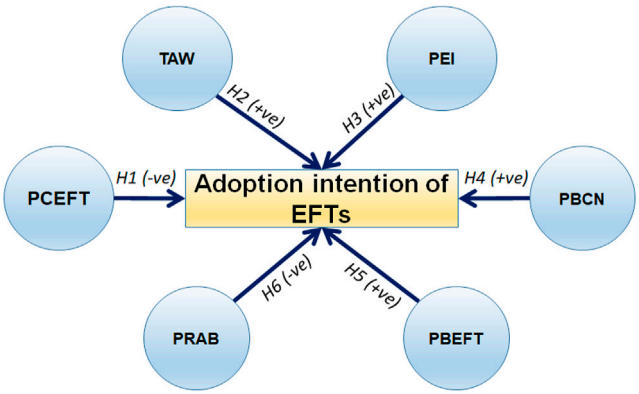

FIGURE 1 | Theoretical background and hypotheses formulation.
Notes: EFTs: environmentally friendly technologies, PCEFT: perceived cost of EFTs, TAW: technological awareness, PEI: perceived environmental importance, PBCN: perceived behavioral control, PBEFT: perceived benefits of EFTs, PRAB: perceived risk-averse behavior.

respondents are analyzed by structural equation modeling (SEM) in terms of measurement and structural models evaluations. The key findings showed that perceived cost of EFTs and perceived risk-averse behavior were inhibiting elements of EFT adoption intention, while others proved drivers of the same. The results offer valuable policy directions for marketers, governments, and policymakers.

The rest of the study follows the following structure: "Theory and hypotheses formulation" discuss TPB and formulate hypotheses in the light of past studies. "Data and methods" describe data and explain the measurement model. The "structural model results and discussions" section is based on the evaluation results of the structural model. Additionally, this section briefly discusses the obtained results in the light of the past literature. The "conclusion" section concludes the study and provides policy directions.

THEORY AND HYPOTHESES FORMULATION

Mainstream theoretical research viewed that households decide on purchasing some product based on various factors. In this regard, several theories include the norm activation model, green perceived value theory, reasoned action theory, and planned behavior theory (TPB). Several scholars postulated that TPB was the most influential theory to explain household behavior (Ajzen, 1985). In this regard (Ajzen and Fishbein, 1970), posited that TPB was based on the following pillars: 1) the attitudes of households towards a behavioral interest, 2) the subjective norms established in the existing society, and 3) the perceived behavioral control of household members to take a particular purchase action. In this study, we consider perceived behavioral control as the TPB factor and incorporate other novel factors in the model to determine the households' perceived adoption intentions of EFTs (see **Figure 1**). We explained each of the considered factors in the following sub-sections.

Perceived Cost of EFTs

Households analyze price details to decide the financial compromises they make when purchasing. The PCEFT is seen as one of the key inhibitors to EFT adoption. Over the past years, past studies have noticed a decline in total EFT costs (Strazzabosco et al., 2020). Though, it is yet to be expanded to the point that it can compete with the solutions that already prevail. EFTs are considered to be expensive and require high costs of early fixation (Goodarzi et al., 2021). Many researchers investigated the negative relationship between PCEFT and the adoption intention of EFTs (Simpson et al., 2021). It has been viewed that a rise in the cost of technology contributes to more aversion from that technology on the part of households. It has been discovered that households' acceptance of EFTs is mitigated in response to the rising costs of EFTs (Tseng et al., 2021). Besides, the developing world identified EFT-associated costs as the major obstacle in EFT acceptance. We formulate the following first hypothesis:

H1: PCEFT is likely to have a detrimental effect on the adoption intention of EFTs by households.

Technological Awareness

Past studies have identified technological awareness (TAW) as an essential factor of innovative technology adoption (Dincbas et al., 2021). TAW may be seen as the understanding of customers, including the related advantages and disadvantages of technology usage, i.e., the prices, the reserves, the competence, and the associated issues. Further, TAW is a vital component in unveiling the households' intention to adopt EFTs. A study in the Malaysian context reported a direct correlation between households' knowledge and their intention regarding the use of new technologies (Shah et al., 2021). Additionally, the objective of the adoption of technology could be associated with its technical benefits or environmental influences. It is also believed that if customers have the know how about the impact of the action they perform on reducing carbon emissions may strive to change the current standard of living and use innovative, sustainable technologies to preserve nature (Kinkel et al., 2021). In this way, for the adoption of new technology and positive environmental impact, it is vital to increase households' understanding of the technological benefits (Toufaily et al., 2021). Because of the low educational training, however, people might not always be well educated about the need for energy-saving and environmental issues. Hence, the lack of awareness has a negative effect on households' adoption of the new technologies (Ullah et al., 2021). Accordingly, we formulate the second hypothesis as:

H2: Households' TAW is likely to have a positive impact on their adoption intention of EFTs.

Perceived Environmental Importance

Perceived environmental importance (PEI) has been described as the level of motivation of households about environmental problems (Shahbaz et al., 2021). In this regard, the majority at the global level recognize the impact of their daily usage behavior on the ecology and focus on reducing risks. These people with ecological concerns seek to protect the environment and display positive word of mouth regarding EFTs (Harley et al., 2020). Researchers are therefore paying closer attention, based on their PEI, to the desire of households to purchase EFTs (Debnath et al., 2021). Identified PEI as the prime element of the environmental priorities of households regarding EFT adoption intention. Households having such environmentally-oriented behaviors are probable to be extremely vigilant about energy use and act more optimistically towards the adoption intention of EFTs. These customers also consider energy efficiency as their own responsibility and view it more optimistically (Ajaz, 2019). The consumption of EFTs by households could be affected by their climate change concerns. In this regard (Broska, 2021), has declared PEI's effect on the energy-saving intentions of households. Based on the author's statement, PEI could be assumed to positively influence their adoption intention of EFTs. So, our third hypothesis is as follows:

H3: PEI of households is expected to positively impact their adoption intention of EFTs.

Perceived Behavioral Control

A person's confidence in their capability to perform behavioral actions is defined as perceived behavioral control (PBCN) (Ajzen, 1985). Such kind of behavioral control may directly affect the intentions of the households and ramblingly influence their behavior. If households are unable to execute any conduct, the conforming intentions shall not be generated (Tian et al., 2021). From EFT's viewpoint, PBCN is about how simple or difficult the potential buyers perceive adoption technology. One function that can activate households' PBCN is connected to technology-related technicalities. PBCN strongly affects households' desire to purchase innovative technologies such as EFTs (Mohanty et al., 2021). It has been viewed that, in order to use new technologies, a person must have accessibility to the means necessary to repair and purchase technologies such as EFTs (Lou et al., 2021). A strong correlation between PBCN and the energy-saving intentions of households has been found to exist. In this context (Wang et al., 2021), stated that PBCN had a significant role to play in the purchaser's choice of vehicle. Finally (Saengavut and Jirasatthumb, 2021), unveiled the beneficial effect of PBC on households' use of energy-efficient electrical devices has been discovered. Further, PBC is a critical element of the intention of households in India and Finland to use bioenergy. Our fourth hypothesis is developed as:

H4: PBCN is expected to yield a positive effect on households' adoption intention of EFTs.

Perceived Benefits of EFTs

Perceived benefits of EFTs (PBEFT) are the innovation experienced by households in terms of the advantages they expect from the technologies such as EFTs with respect to their costs (Manika et al., 2021). The households compare the EFTs with traditional sources of energy and make decisions from a general socio-economic perspective. For the most part, households are searching for a commodity that is comparatively cheap, easy to consume, and delivers innovations in the long run (Chen et al., 2019). EFT development has been noted to be sluggish since the promotion of their associated PBEFT has been lacking in the society (Xie and Huang, 2021). Found that the PBEFT comprises prices, social factors, or certain other forms of behavior. PBEFT is assured if a new product provides more value, has a small option base, and also compensates if customers choose to turn to the previous one again (Ediriweera and Wiewiora, 2021). However, the actions of households against new technology affect PBEFT. Thus, PBEFT is expected to intervene directly with attitude towards EFTs and not have a direct association with the plan to adopt EFTs (Yang et al., 2021). Our fifth hypothesis is given as:

H5: PBEFT is expected to have a positive effect on the households' adoption intention of EFTs.

Perceived Risk-Averse Behavior

Perceived risk-averse behavior (PRAB) is the risk associated with household buying behavior of an innovative product such as EFTs. A survey has been conducted in rural India, and the findings showed that the findings indicate that both household spending and savings and the entrepreneurial mindset of the head of the household are good determinants of adoption. On the other hand, past fuel spending, risk tolerance, and people's trust are not correlated with implementing the technology (Aklin et al., 2018). This study explores the willingness of farmers to engage in a special, manure-driven collective investment in biogas driven by Danish farmers' discrete choice experiment. The findings indicate that most farmers, including farmers who had never previously contemplated investing in biogas and farmers who are still involved in traditional biogas plants, are interested in a partnership-based investment in biogas (Zemo and Termansen, 2018). A survey was conducted in Lebanon by using the diffusion of innovation model. A sample of almost 200 participants has been taken, and the outcome showed a significant difference among users and non-users of renewable energy in terms of size of households and their earnings (Elmustapha et al., 2018). The research draws on a representative sample of the population of Austria. The results indicate that the renewable energy view is more closely correlated with approval in the group of participants concerning renewable energy development (Sposato and Hampl, 2018). Given these studies' results, our sixth hypothesis is given as:

H6: PRAB is likely to impart a negative effect on households' adoption intention of EFTs.

DATA AND METHODS

Data Gathering and Analytical Tool

The measurement items for the perceived cost of EFTs (PCEFT) were adapted and modified from (Jabeen et al., 2019). The items

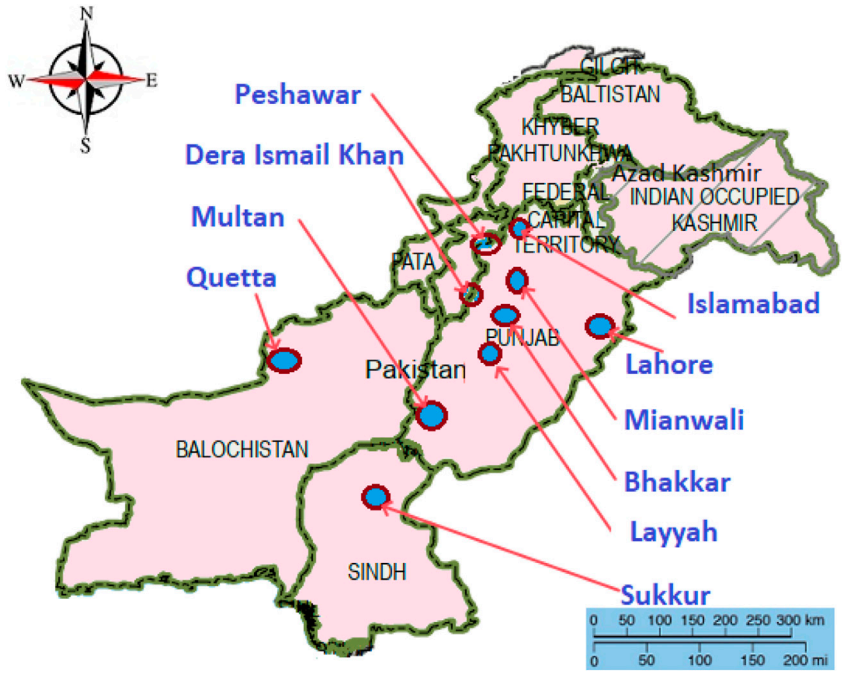

FIGURE 2 | The geographical location of our research.

for technological awareness (TAW) were taken and modified from (Fatima et al., 2021). The items concerning the perceived environmental importance were based on (Jabeen et al., 2021b). Then, the perceived behavioral control's (PBCN) items were borrowed from (Shakeel and Rahman, 2018). After that, the items regarding the perceived benefits of EFTs (PBEFT) were adapted and modified from (Jabeen et al., 2021a). Besides, the items for perceived risk-averse behavior (PRAB) were taken and modified from (Ahmad et al., 2020). Finally, the items for adoption intention of EFTs (AIEFT) were borrowed and modified from (Ahmad et al., 2021a) and (Irfan et al., 2021). We used a Likert scale varying from 1 = strongly disagree to 5 = strongly agree. The survey data were gathered from 782 households in selected ten cities (Islamabad, Mianwali, Lahore, Bhakkar, Layyah, Multan, Peshawar, Sukkur, Quetta, and Dera Ismail Khan) of Pakistan during February 2021-June 2021. The geographical location of the research is shown in **Figure 2**. Around 895 questionnaires were circulated, out of which 782 were valid for final analysis, constituting around 87.37% response rate. Structural equation modeling (SEM) analysis has been applied to estimate the measurement and structural models using the statistical software Amos-26.

Demographic Attributes of Data

Table 1 has given the demographic attributes of respondents at the survey location. The main portion of respondents were youngsters (43.73%) and middle age people (42.84%), while older had the least proportion. The male (63.81%) exceeded the female (36.19%) respondents. The married respondents contributed the most substantial proportion (59.46%), followed by the not-married category respondents (31.08%). The respondents were mainly master degree holders (50.13%), while bachelor degree holders and primary/secondary schooling respondents contributed more or less equal proportions. Finally, most respondents (65.60%) were from the middle level of income (170,000–840,000), followed by the low and high level of income, respectively.

Measurement Model

We calculate the square root of the average variance extracted (AVE) to check whether our data established the discriminant validity. **Table 2** shows the findings of discriminant validity based on the benchmark of (Fornell and Larcker, 1981). The results exposed that the cross-correlations of the latent constructs did not exceed their self-correlation values, confirming the evidence of discriminant validity in our data. Next, for the measurement model, we use confirmatory factor analysis (CFA). To this end, composite reliability (CR), average variance extracted (AVE), and Cronbach-alpha are calculated for convergent validity and reliability analysis (Hair et al., 2014). Given the AVE values exceeding 0.50, it implicated that the observed items account for more than 50% of latent construct variations (Ketchen, 2013). Finally, the factor loadings for each observed item of all the six latent constructs exceeded the minimum threshold value of 0.70, suggesting the convergent validity of the measurement model. Based on these results, the measurement model is valid and directs towards the estimation of the structural model. **Table 3** displays the measurement model results.

TABLE 1 | Demographic attributes of respondents.

Demography	Categories	No. of respondents	Proportion (in %)
Age (in years)			
Youngsters	18–30	342	43.73
Middle age	31–50	335	42.84
Old age	50+	105	13.43
Sex			
	Males	499	63.81
	Females	283	36.19
Mariage state			
	Married	465	59.46
	Not married	243	31.08
	Divorced/widowed	74	9.46
Qualification level			
	Primary schooling	89	11.38
	Secondary schooling	142	18.16
	Bachelor degree	151	19.31
	Master degree	392	50.13
	Doctoral degree	8	1.02
Income level (PKR per year)			
Low level of income	<170,000	173	22.12
Middle level of income	170,000–840,000	513	65.60
High level of income	>840,000	96	12.28

Note: PKR: Pakistani rupee (local currency unit).

TABLE 2 | Discriminant validity based on (Fornell and Larcker, 1981).

Factors	PCEFT	TAW	PEI	PBCN	PBEFT	PRAB	AIEFT
PCEFT	[0.89]						
TAW	–0.429	[0.83]					
PEI	0.392	0.563	[0.88]				
PBCN	0.411	–0.656	0.583	[0.86]			
PBEFT	0.518	0.245	0.476	0.475	[0.80]		
PRAB	0.329	–0.637	0.580	0.573	0.367	[0.87]	
AIEFT	0.128	0.185	0.364	0.684	0.648	0.462	[0.81]

Notes: The brackets [] enclosed the square root of AVE values.

STRUCTURAL MODEL RESULTS AND DISCUSSIONS

Table 4 provides the results of the structural model. The structural model aims to test the hypothesized relationships of household perception factors (independent variables) with the adoption intention of EFTs (dependent variable). The structural model is evaluated under the following steps. First, the R^2 value assesses the amount of variability in the dependent variable due to independent variables. In the present case, the R^2 value of 0.630 shows 63% variability in the dependent variable (AIEFT) is explained by the independent variables (i.e., PCEFT, TAW, PEI, PBCN, PBEFT, PRAB), which is substantially greater than 0.350, confirming the sufficient explanatory power of the structural model (Anderson and Gerbing, 1988). Second, the Q^2 value (0.428) shows a sufficient amount of predictive relevance of the constructs in our structural model. Third, the variance inflation factor test for multicollinearity (VIFT) shows that there is no multicollinearity in the model since all the scores of VIFT are less than 10 (Hair and Babin, 2017). Lastly, the beta coefficients of independent variables remained significant at a 5% level of significance (i.e., $p < 0.05$), holding all the structural paths to be relevant. The beta coefficient for PCEFT is negative, while the coefficients for all other variables are positive. Thus, the results supported all our hypothesized relationships. Thus, the hypotheses that TAW, PEI, PBCN, and PBEFT positively drive individuals' adoption intention of EFTs, while PCEFT and PRAB inhibit such adoption behavior. The findings of beta coefficients are given in **Table 4** and in **Figure 3**.

Based on findings, the TAW, PEI, PBCN, and PBEFT are identified to be the positive contributors to households' adoption intention of EFTs, whereas PCEFT and PRAB extended negative contributions. Regarding the positive contributors, technological awareness and environmental importance shape households' preferences to adopt EFTs greatly, considering thsem the solution for environmental issues. Likewise, given some incentives, it is expected to enhance AIEFT because households are likely to respond to incentives. In the same vein, the better quality and durability of the EFTs are expected to promote AIFT. Therefore, PBEFT has shown a pushing contribution to AIEFT. On the contrary, being risk investments and offering high installation costs induce impediments in adopting EFTs.

Considering the prioritization ranking of the factors, PEI got the highest priority based on its highest *f*-square score. The PBEFT received the second-highest priority among the considered factors, followed by PCEFT, PBCN, and TAW. Finally, PRAB had the least priority among all the factors. These prioritizations are shown in **Figure 4**. Each of the driving and inhibiting factors is discussed one by one, as follows.

PCEFT and EFT Adoption Intention

Our first finding of PCEFT confirmed our assumption by showing an inhibitory impact of PCEFT on households'

TABLE 3 | Measurement model results.

Constructs/scale items	Factor loading	AVE	CR	C-α
Perceived cost of EFTs (PCEFT)		0.787	0.801	0.750
PCEFT1	0.757			
PCEFT2	0.793			
PCEFT2	0.839			
Technological awareness (TAW)		0.748	0.853	0.725
TAW1	0.810			
TAW2	0.847			
TAW3	0.826			
TAW4	0.802			
Perceived environmental importance (PEI)		0.756	0.872	0.731
PEI1	0.795			
PEI2	0.848			
PEI3	0.759			
PEI4	0.811			
PEI5	0.765			
PEI6	0.820			
Perceived behavioral control (PBCN)		0.734	0.765	0.723
PBCN1	0.824			
PBCN2	0.729			
PBCN3	0.775			
Perceived benefits of EFTs (PBEFT)		0.751	0.813	0.701
PBEFT1	0.791			
PBEFT2	0.825			
PBEFT3	0.798			
PBEFT4	0.809			
Perceived risk-averse behavior (PRAB)		0.738	0.825	0.718
PRAB1	0.746			
PRAB2	0.880			
PRAB3	0.831			
Adoption intention of EFTs (AIEFT)		0.745	0.799	0.713
AIEFT1	0.758			
AIEFT2	0.801			
AIEFT3	0.792			

Note: AVE: average variance extracted, CR: composite reliability, C-α: Cronbach alpha.

TABLE 4 | Structural model results.

Hypotheses	Hypothesized link			Beta	Decision	VIFT	f^2	R^2	Q^2
H1	PCEFT	→	AIEFT	−0.435*	Relevant	1.367	2.383	0.630	0.428
H2	TAW	→	AIEFT	0.368*	Relevant	2.092	2.016		
H3	PEI	→	AIEFT	0.520*	Relevant	1.883	2.849		
H4	PBCN	→	AIEFT	0.391*	Relevant	1.571	2.142		
H5	PBEFT	→	AIEFT	0.476*	Relevant	2.095	2.608		
H6	PRAB	→	AIEFT	−0.310*	Relevant	2.518	1.698		

*Note: *p < 0.05.*

AIEFT. In fact, the EFTs are costly compared to the traditional electricity storage activities, and the additional expenses of buying become an obstacle to their acceptance. The existing works in the context of European EFTs' markets also revealed that the high cost of EFTs at times inhibits prevalent acceptance of EFTs (Linzenich et al., 2019; Zhou et al., 2019). For instance, installing photovoltaics for household customers is four to five times more costly than other on-the-market power generation strategies such as urgent power supply (UPS) and oil-fired power generators (Tseng et al., 2021). The costs are significantly higher than usual for a regular household to pay at once. The analysis assisted the results of the earlier research by (Strazzabosco et al., 2020), in which the price is subjected to negative effects on the desire of customers to accept EFTs. It states that the price is a substantial barrier in the succession plan of the households to adopt EFTs.

TAW and EFT Adoption Intention

Our second result showed a positive impact of TAW on households' adoption intention of EFTs in Pakistan. Our

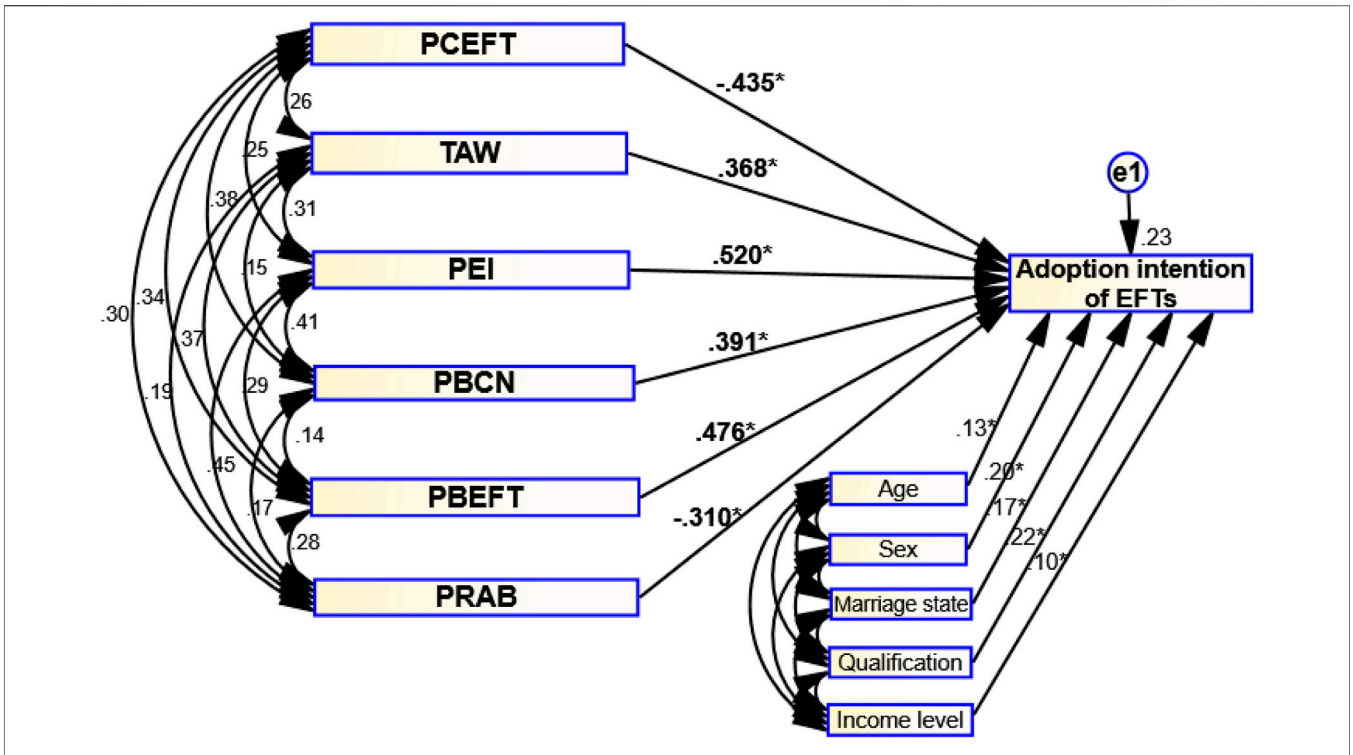

FIGURE 3 | Structural modeling results. Note: *$p < 0.05$ shows the significance level at 5%.

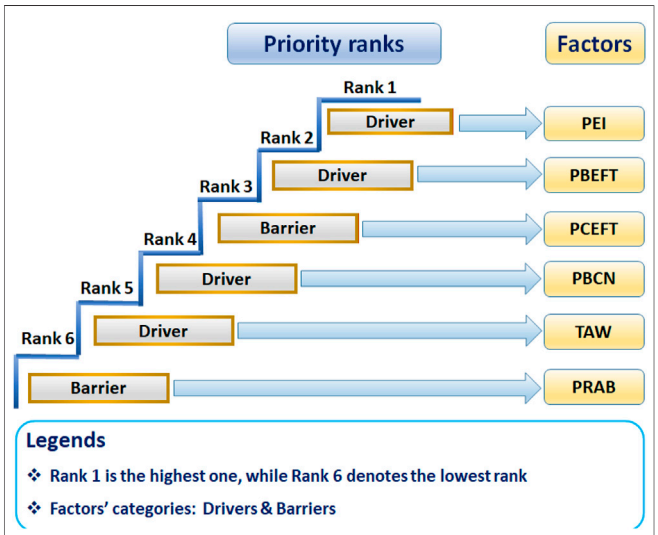

FIGURE 4 | Prioritization ranks of factors affecting households' adoption intention of EFTs. Source: Prioritization is based on *f*-square scores of the structural model.

analysis denies the outcomes of former research that discovered a discouraging effect of awareness on using innovative technologies (Kinkel et al., 2021). Their potential explanation was that the households were not completely educated about the new technologies and their linked benefits. Earlier research by (Dincbas et al., 2021) stressed that household awareness about the usefulness of EFTs plays a significant role in determining the adoption of those technologies. There is a lack of awareness of the wholesalers, equipment, and implementation services that can be reliable and can be useful in the long run in Pakistan (Jan and Akram, 2018).

PEI and EFT Adoption Intention

Our third result revealed that PEI imparted a positive influence on the EFT adoption intention of households. In the United States, the households believed that the dependence on imported oil was reduced by using new energy technologies. They considered it an eco-friendly option (Ajaz, 2019). It has been believed that households are sensitive to emotions associated with environmental concerns, which may provide the spark to adopt EFTs (Zhang et al., 2015). Also, the works done in the United States, China, and Germany uncovered that households with enhanced preferences towards environmental concerns are more likely to adopt EFTs (Harley et al., 2020). It has been argued that the households also feel an emotional advantage as they contribute positively by making the environment less degraded (Michelsen and Madlener, 2013). This is widely recognized that using EFTs tends to make the air comparatively healthy and can reduce production-related contamination (Broska, 2021). Based on the former studies, it was believed that the same impact might likely take place on the market in Pakistan. Also, one possible intent may be correlated with the key explanation why customers took on the EFTs. Aspects applicable to the climate may be used as a guideline for households in those states where the technology is used as a replacement for long-term benefits, reduce spending

on energy, or invest constructively in environment-related sustainable plans (Shahbaz et al., 2021). The emissions or environment-related problems are usually crucial for households in Pakistan when drawing up these assessments.

PBCN and EFT Adoption Intention

Our fourth finding indicated that the PBCN's effects are positive on using EFTs. The implications of this research are aligned with the findings of an earlier study revealing that the PBCN positively affected the buyers' willingness to use EFTs (Saengavut and Jirasatthumb, 2021). EFTs are considered relatively complicated to use than predominant on-the-shelf sources of power production such as UPS and power generators. Repair and maintenance expenses, lack of professional knowledge, expertise accessibility, very limited possession, and without prior understanding of using EFTs, the implementation of such technologies can be troublesome. Households' views regarding the potential use of innovative technology such as EFTs are crucial factors in establishing EFT dependence.

PBEFT and EFT Adoption Intention

Our fifth finding uncovered that the PBEFT positively affected the decision to use EFTs. Regarding the benefits of using EFTs, different from the conventional technologies, the EFTs offer extra benefits in terms of energy-saving, reduction in bills, help in making the environment clean, and decreasing the production of pollutants (Shaharudin et al., 2019). Our results also confirm some previous findings (Yang et al., 2021). Within a developing world such as Pakistan, purchasing decisions by households are dependent on the perceived benefits of a specific commodity (e.g., EFTs) they are going to purchase. If households know its perceived benefits, they would be ready to pay more for such technologies (Chen et al., 2019). Furthermore, (Manika et al., 2021), claimed that a relative benefit of some technology could guarantee that the households had a choice to replace the latest technology with the earlier one.

PRAB and EFT Adoption Intention

Our final finding discovered a negative and significant impact of PRAB on households' adoption intention of EFTs. On consumer psychology grounds, innovative technologies like EFTs could involve high risk for households making them risk-averse and preventing their intentions to adopt EFTs (De Pinto et al., 2013). Hartmann et al. (2013) narrated that there were psychological advantages of using EFTs, implying that the households' psychology matters for shaping the households' adoption behavior of EFTs. Contrastingly, to avoid environmental pollution, EFTs appeared among positive role-playing dimensions. However, some studies stated that the investment risk associated with EFTs was determined to be a negative role player in the adoption decision process (Yu et al., 2021). Additionally, Shimbar and Ebrahimi (2020) investigated and suggested that foreign investments in new technologies encouraged environmental emissions mitigation in developing countries. Data consisting of 105 farmers have been collected in Switzerland to investigate taking measures to combat agricultural and ecological issues. The results showed the influence of risk perception on taking measures (Kreft et al., 2020).

CONCLUSION AND POLICY RECOMMENDATIONS

This study analyzed the households' perception factors in determining the adoption intentions of EFTs. The case of Pakistan has been considered for data collection and exploration. An SEM methodology is used to estimate the empirical results. The main conclusions are as follows: 1) technological awareness, perceived environmental importance, perceived behavioral control, and perceived benefits of EFTs proved as significant drivers of adoption intentions of EFTs. 2) The perceived cost of EFTs and perceived risk-averse behavior of households were revealed to be the barriers to adopting EFTs. 3) Based on prioritization ranking, perceived environmental importance was the highest ranked, while perceived risk-averse behavior was the lowest-ranked factor determining adoption intention of EFTs.

Based on our results, the following policies are suggested. The financial benefits, including discounts and subsidies, would positively shape the buying behavior of households towards EFTs. Therefore, the roaring cost of EFTs should be controlled to impart its positive influence on the adoption intention of EFTs by households. Moreover, the provision of rebates and subsidization is obligatory for the development of EFTs in any country. Along these lines, the governments must take these issues into account since much has to be done to keep households aware of environmental issues and their responsibility towards environmental protection and environmental sustainability. Though this research provided reflective progress, it could not capture all the environmentally friendly technologies. Future studies should be focused on each individual environmentally friendly technology to yield technology-specific findings.

DATA AVAILABILITY STATEMENT

The research data from this article will be available by request from the corresponding authors.

AUTHOR CONTRIBUTIONS

NF: Conceptualization, writing-original draft, variable construction, formal analysis. YL: Supervision. WA: Writing-review and editing, Visualization, Software. GJ: Data curation, Writing-review and editing, methodology. TZ: Writing-review and editing, Software. XL: Writing-review and editing. AY: Writing-review and editing. CI: Writing-review and editing. NA: Writing-review and editing, methodology. MA: Writing-review and editing, methodology, Formal analysis.

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Combing Effects of Economic Development and Globalization Towards Energy Efficiency and Environmental Degradation: Fresh Analysis From Energy Efficient Resources

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How much environmental pollution can be reduced by the efficient use of financial, natural, and energy resources in the current globalization. Thus, this study provides empirical evidence in support of the theoretical argument by investigating the impact of financial development, environmental assets, globalization, coal, natural gas, and sustainable carbon emissions in 32 developed countries from 1990 to 2018. Ecological degradation (estimated by carbon dioxide emissions) experienced a structural shift that was considerably more pronounced in 2000–2011 than in 1991–1998. A broad variety of econometric methodologies (such as the Chow test, Cross-country regression, and the Generalized Method of Moments (GMM)) were applied. As a consequence, environmental deterioration is strongly linked to economic development and urbanization, according to the findings. These nations' ecological footprints are favorably influenced by financial development, environmental assets, and non-renewable energy, whereas globalization and sustainable sources have a negative impact. Environmental degradation may be slowed by combining globalization's impact on financial growth with the conservation of natural resources such as renewable energy sources. In order to improve their economic and ecological resource frameworks, these nations will need to increase their use of solar and other renewable energy.

Keywords: CO_2 emission, globalization, financial inclusion, Chow and GMM estimator, energy effciency

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1 INTRODUCTION

There was a 1.37-fold rise in global carbon emissions in 2018 as compared to 1970, reaching 33,890.80 million tonnes. The 32 developed countries members are among the world's leading polluters. In 2018, the 32 developed countries nations' carbon emissions were 8611.80 million tonnes, or 25.41% of world emissions (Kordej-De Villa and Slijepcevic, 2019). A thorough investigation of the G7 nations' carbon dioxide emissions is essential to reducing world pollution, throughout the globe for more than 30 years because of the devastating implications for human lives, such as the devastating earthquake and the tsunami that struck Indonesia. The Intergovernmental Panel on Climate Change (IPCC) (2007) report was published a little over

10 years ago and indicated that global warming is the most unparalleled and difficult challenge facing the planet's population. Global climate change is evident, as shown by rising ocean temperatures and sea levels, a rise in greenhouse gas emissions, as well as a decrease in the quantity of snowfall. In industrialized countries, the UN estimates that about half of the world's population is economically alienated; in emerging countries, however, the number is much higher. There are several advantages to an organization's financial statements that eliminate obstacles to access for the most underprivileged members of society (Zhang Ke et al., 2021). Inequalities in the holding of bank accounts by gender in underdeveloped nations are enormous. For example, the percentage of males who have a regular account is 46%, while the percentage of females is 37% (Charity et al., 2021).

As business investment grows, so do CO_2 emissions, making it the most prevalent global warming gas, (Kong and He, 2020; Wang and Hou, 2020; Lei et al., 2021). There's been a steady rise in CO_2 emissions in emerging nations over the years, with 32 developed countries becoming the world's biggest producer of the gas. Because its per capita total emissions are just approximately a quarter of the global average of 4.6 tonnes, Africa has been dubbed a greenhouse gas emission model. With the world's lowest GDP, safe drinking water, and construction and transportation activities in the country, as a result, it is critical to investigate the factors that lead to these releases in order to implement measures to prevent them from reaching catastrophic levels. It is possible to decrease unemployment and weather climate resilience through increasing financial inclusion. Financial inclusion raises the topic of how it affects CO_2 emissions. According to rational thought, providing families and small businesses broader access to financing would inevitably lead to a rise in carbon dioxide emissions (Yun et al., 2017; Arenliu et al., 2021).

Financial inclusion has been shown to have a positive influence on the economy and society, but less is known about how it affects the efficiency of the banking sector (Bai et al., 2018; Kordej-De Villa and Slijepcevic, 2019). Economic development may be encouraged by banks' vital role in distributing limited financial capital, which they do as an integral element of banking institutions (Bai et al., 2010; O'Neill et al., 2020). Credit ratings and corresponding economic upheaval drew interest in recent years in financial deepening and unhealthy behaviors, although this was before the economic meltdown (Wang et al., 2020). In order to avoid systemic crises, it is essential to analyses the connectivity between financial inclusivity and credit worthiness (Wu et al., 2021). To reap the benefits of the developing financial industry (Sellitto et al., 2020) is not inexpensive, though. Effective use of energy can be achieved thanks to a well-developed banking system, and environmental standards may be enacted with little expense and maximum funding (Ahmad et al., 2021). In the present research, there is a clear connection between certain robust banking systems and sustainability inadequacy (Salahodjaev 2016; Pakseresht et al., 2020). Furthermore, financial inclusion helps strengthen banks. A significant ideological authority and a sophisticated banking culture may encourage banks to take more risks, whereas a thriving business and favorable regulatory conditions are more likely to foster this type of linkage. As a result, we conclude that increasing financial inclusion may improve financial reporting quality by enhancing asset diversification and securing financing sources. The study's second goal is to examine how resources affect the contribution to climate change. Resources with a low ecological footprint, such as crops, woods, developed lands, fishing waters, and livestock areas, offset the greenhouse gas emissions caused by humans and ease the flow of money for energy production (Wang et al., 2018). Environmental performance is negatively impacted by several conventional natural resources such as coal, gas, and hydrocarbons. Environmental habitats, on the other hand, have been shown to have a significant impact on economic growth and actual income. Natural resources like oil and gas are used in the early stages of economic expansion without regard to their environmental impact (Mohsin et al., 2021; Zhang Dongyang et al., 2021).

The focus of the present research will be to analyses the role of sustainable and non-renewable energy requirements in re-evaluating the contamination function as well as determining the ecological integrity of financially resource-rich nations (Li et al., 2021; Iqbal et al., 2021). Similar to the awareness of sustainable integrity, fossil fuels also have a significant influence. The empirical statistics were performed to better understand the impact of non-renewable and ecofriendly carbon emissions on the contribution to global warming. This allows us to make more appropriate policy suggestions. For the present form of economic growth to continue and accomplish the SDG objectives, it is necessary to identify the differences in environmental conservation between sustainable and non-renewable energy use. There is still a major vacuum in the empirical literature when it comes to considering the various impacts of different kinds of energy sources. To sum up, this work contributes to the empirical literature in the fields of budgeting and operational finance as well as ecological finance.

There are five ways in which this study differs from previous studies: Furthermore, this research examines the connections between economic development, natural resources and ecological footprints, comprising non-renewable energy, concurrently throughout the paradigm of globalization. To the best of the author's knowledge, this is the first study to examine the relationship between these characteristics and the wealthiest nations in the world. (iii) Rather than carbon dioxide emissions, the entire ecosystem is used as a yardstick for environmental damage. Appropriate environmental data is provided by the six environmental indicators (i.e., built up land (buildings), grazing, fishing ground, forests, and carbon footprint. Furthermore, this research employed the International Monetary Fund's (IMF) recommended financial development index to encompass the many aspects of economic advancement, such as the comparative country ranking in terms of experience, availability, and efficiency of government advancement. It also gives a new way to examine the influence of financial growth, globalization, and renewable energy on land and resources as potential moderators. A complete knowledge base for formulating policies pertaining to financial advancement, environmental resource use, and alternative energy use during globalization can be found by

investigating the vague associations between economic growth, globalization, sustainable energy demand, and biological capital. This will be helpful to help policymakers recognize a new understanding of environmental viability. This investigation was based on the fact that the Chow test, and the Generalized Method of Moments (GMM) were all used in this study (v) Eventually, G-7 will have a lot of financial resources and be able to actually implement the SDGs. To sustain ecological quality, it is essential to know how this nation with a great quantity of economic, ecological, and resource utilization uses these resources. This study's important results underline the need for effectual and environmentally sound strategies for recently introduced business and monetary advancement and sustainable and clean energy and emission development that do not pose detrimental ecological problems for this country.

The remainder of the article is arranged as follows: **Section 2** is a review of the literature. **Section 3** presents the data sources and methods. **Section 4** contains the results and commentary. Conclusions and policy implications are covered in **Section 5**.

2 LITERATURE REVIEW

Analysis of the effect of financial accessibility among nations is done in two key ways in the effect of financial inclusion. Financial inclusion indices may be constructed in two ways: 1) by evaluating relevant financial factors independently, and 2) by generating multivariate indexes. By creating comprehensive financial inclusion indexes employing specific measures of financial services accessibility, scholars like (Wu et al., 2020; Omri and Bel Hadj, 2020) have begun to explore collective data on financial availability. They said that complex and multifaceted compound indexes may be used as a meter for measuring context's effectiveness. Scholars and practitioners can compare nations holistically using a multivariate financial inclusion index since it comprises collected data about several characteristics of direct investment in a country. According to the World Bank, "there is surprisingly little empirical research investigating the particular connection between financial inclusion and greenhouse gas emissions" (Fonseca et al., 2015; Ahmadi et al., 2017). Relevant data on financial inclusion across nations is rare and inconsistent, which is one of the reasons behind this assumption (Samimi et al., 2012; Li et al., 2018).

In the aftermath of the global financial crisis, scientific literature has been pushed to the forefront, although the findings are mixed. Prior research believes that business access and use has a long-term effect on financial stability. In (Barbier, 2016; Ikram et al., 2020) they do a cross-country study. Ecological deterioration and infrastructure prosperity have been studied in a variety of ways since Grossman and Krueger's classic study (1994). According to the authors, in the preliminary stages, industrial development is closely linked to a rise in carbon dioxide emissions. However, when the degree of expansion is above a specific threshold, the opposite occurs. However, although some of these investigations have shown evidence for the EKC (Irfan et al., 2021) and several others have found no support for the EKC (Morrow and Rondinelli, 2002).

To compensate for unobserved heterogeneity in light of multiple research's inconsistent findings, many now add monetary development. This is because the capital structure is expected to have positive impacts on economic emissions and water quality. Accelerated market production (the wealth impact) should, in theory, lead to higher energy use and carbon dioxide emissions. Finances may also lead to involvement in more modern technology (technical impact), resulting in lower greenhouse gas emissions and better energy consumption (effectiveness) (Park and Pyun, 2020). In order to have a good impact on the environment, financial growth relies on attracting foreign direct investment (FDI) and its accompanying R & D (Hutson and Laing, 2014). Energy consumption and ecological impact are linked by looking at the nations' real income growth patterns. There is a massive market for coal and oil as a result of rising income levels. It emits air pollutants into the environment as a result of increasing greenhouse gas emissions after this technique. Thus, environmental quality is a worry to some degree because of the significant income growth trend. After a certain point in this expansion, a gain in environmental understanding encourages businesses, government agencies, and lawmakers to priorities conventional energy sources and less polluting technology.

Energy consumption and ecological impact may be explained by looking at the nation's gross domestic product. There is a growing demand for energy production as a result of rising income levels. It emits air pollutants into the environment as a result of enhanced non-renewable sources after this technique. Thus, ecological perfection is a worry to some degree because of the significant income projection growth. A rise in ecological expertise endures among businesses, supranational institutions, and governments when this development process reaches a minimum threshold. If a well-functioning, efficient, and well-developed financial sector contributes to the gross domestic product, it is logical to speculate that something has ecological impacts. (Allayannis and Ofek, 2001) Similarly, effectual and well-functioning economic growth helps the gross domestic product (Kim et al., 2020). It is possible, though, that the hopeful role of a well-developed financial framework in promoting economic development may lead to increased energy consumption and ecological concerns (Bodnar and Wong, 2003). Financial growth and the destruction of the environment are intertwined, but the research information on this dynamic relationship is overloaded with scientific findings that are inconsistent, contradictory, and conflicting.

3 DATA AND METHODOLOGY

Our model of the causes of ecological degradation is obtained through various reviews (White, 1980; Storn and Price, 1997) looks like this:

$$\ln CO2_{it} = \beta_1 + \beta_2 \ln GDP_{it} + \beta_3 \ln URB_{it} + \beta_4 \ln TR_{it} + \beta_5 \ln FD_{it} + \beta_6 IQ_{it} + \beta_7 \ln FD_{it} * IQ_{it} + \varepsilon_{it} \quad (1)$$

where the subscripts i *and* t represent the country and era, respectively; is the logarithm of greenhouse gas emissions $\ln CO2_{it}$, is the logarithm of gross domestic product $\ln GDP_{it}$, is the logarithm of urbanization $\ln URB_{it}$, is the logarithm of globalisation $\ln TR_{it}$, is the logarithm of economic development, IQ and is the measurement error ε_{it}. The Chow test is used to confirm that our framework is dependable by accounting for possible failure mechanisms. The analysis is used in a multiple regression situation to see whether the slope of two-time intervals varies. The following is a summary of the Chow test's mechanism. This allows us to use a joint F-test to determine the structural stability of regression slopes, which becomes significant when there is a fundamental breakdown or shift in the statistics. When we apply the Chow test to **Eq. 1**, we get:

$$\ln CO2_{it} = \beta_0 + \beta_1 \ln GDP_{it-1} + \psi_0 D_t + \psi_1 D_t * lnCO2_{it-1} + \psi_2 D_t * \ln GDP_{it-1} + \varphi_i Z_i + \varepsilon_{it} \quad (2)$$

The significant differential variable is financial inclusion, which is measured by producers and consumers. But the social investment metrics use various units, scales, and variants. To standardize these variables before transforming them into a composite measure, two techniques are used: z-score and min-max. Then Principal component analysis is used to these normalized indicators.

$$\mathrm{ZGLO_{it}} = \sum_{j=0}^{k/2} (j+1)\mathrm{GLO_{it-j}} + \sum_{j=k/2+1}^{k=4} (k-j+1)\mathrm{GLO_{it-j}} \quad (3)$$

To include the four lag distributions of the globalization factor into the framework, we modify **Eq. 1** into **Eq. 4**:

$$\ln(\mathrm{EFP_{it}}) = \beta_0 + \beta_1 \ln(\mathrm{FD_{it}}) + \beta_2 \ln(\mathrm{NRR_{it}}) + \beta_3 \ln(\mathrm{NREC_{it}}) + \beta_4 \ln(\mathrm{REC_{it}}) + \lambda_1(\mathrm{GLO_{it-1}}) + \lambda_2(\mathrm{GLO_{it-2}}) + \lambda_3(\mathrm{GLO_{it-3}}) + \lambda_4(\mathrm{GLO_{it-4}}) + \mu_{it} \quad (4)$$

Where,

$$\lambda_j = \begin{cases} (j+1)\lambda 0 \le j \le k/2 \\ (k-j+1)\lambda k/2 + 1 \le j \le k \end{cases}$$

This extra association parameter (FDitZGLOit) will allow for a considerably more thorough examination of the influence of financial methodologies on environmental stewardship maintenance. This research explores **Eq. 6** as followed in an attempt to prove this research hypothesis:

$$\ln(\mathrm{EFP_{it}}) = \beta_0 + \beta_1 \ln(\mathrm{FD_{it}}) + \beta_2 \ln(\mathrm{NRR_{it}}) + \beta_3 \ln(\mathrm{ZGLO_{it}}) + \beta_4 \ln(\mathrm{NREC_{it}}) + \beta_5 \ln(\mathrm{REC_{it}}) + \beta_6 \ln(\mathrm{FD_{it}} * \mathrm{ZGLO_{it}}) + \mu_{it} \quad (5)$$

Where financial inclusion is concerned i, t represents the growth of bank I in country j in year t, and FI, t represents the financial inclusion indicator, namely FI mm or FI sf in country j. Banki, j, t-1 is a set of bank individual characteristics of a bank i. A one-year lag of bank characteristics is employed to ease the endogeneity issue j, t represents parameters defining the macroeconomic stability of a nation. The year denotes the year of dummies. The idiosyncratic error is i, j, t.

$$\ln(\mathrm{EFP_{it}}) = \beta_0 + \beta_1 \ln(\mathrm{FD_{it}}) + \beta_2 \ln(\mathrm{NRR_{it}}) + \beta_3 \ln(\mathrm{ZGLO_{it}}) + \beta_4 \ln(\mathrm{NREC_{it}}) + \beta_5 \ln(\mathrm{REC_{it}}) + \beta_6 \ln(\mathrm{NRR_{it}} * \mathrm{REC_{it}}) + \mu_{it} \quad (6)$$

On the other hand, it is clear that a large majority of the examined sequences have a direct impact on performance. Furthermore, the averages for lnEFP, the average for lnNRR, the averages for the other variables, lnGLO, the averages for the other variables, and lnREC were all different from the averages by .6214, .2125, 3.6547, .0842, .3117, .8766, .25436, and 3.594 accordingly.

According to bivariate correlation analysis, all factors have somewhat favorable correlations with CO_2 emissions, as shown in **Table 1**. There is also a negative association between economic development, globalization, renewable energy, and the reduction of financial services for non-renewable power consumption. Furthermore, positive bivariate relationships between economic development, globalization, sustainable and non-renewable energy, and energy wealth have been established. Renewable sources and both of globalization's interaction variables have an allowable bivariate association.

3.1 Data Sources

According to this study, the 32 developed countries financially resource-rich nations, which include the United States, United Kingdom, France, Italy, Germany, Japan, and Canada, are analyzed using data from 1990 to 2016. The following parameters are used in this article's empirical analysis: As per the ecological footprint (EFP) and financial development index (FD), countries are ranked based on the complexity, accessibility, and performance of their financial systems. We have modified this financial development index to a scale of 0–100 (Genest et al., 2009) in order to make it interoperable with certain other sequences. It is quantified in terms of aggregate cultural, geopolitical, and reporting data from international globalization. (GLO) Comprehensive resource rents are calculated as a percentage of gross domestic product by combining the rents for fossil fuels. Because of this, NRR was chosen because it takes into account the prices for consumers of domestic manufacturing and extracting. Energy consumption measured in kilos of oil equivalency per capita (NREC) and as a percent of total final energy usage (REC) from thermal, solar, hydroelectrical, and nuclear power plants is included in REC. FD and GLO data are sourced from the IMF, GLO data from (Magnus and Vasnev, 2015) and NRR, NREC, and REC data are sourced from the World Bank database (Shen et al., 2020). **Table 2** defines Stability of the structure with the help Chow test. Chow test can accurately described it.

TABLE 1 | Descriptive and inferential statistics of variables.

Stats	lnEFP	LnFD	lnNRR	lnZGLO	lnNREC	lnREC	lnFD∗lnZGLO	lnNRR∗lnREC
Mean	2.534	3.674	−2.7854	5.754	3.643	2.665	12.956	.112
Median	2.894	5.804	−3.595	5.098	3.779	3.568	12.6745	−0.511
Maximum	1.784	3.675	1.884	5.685	5.095	4.647	12.8747	5.794
Minimum	−2.757	2.795	−3.795	4.895	4.786	−0.765	9.7567	−3.795
Std. Dev.	.621	.212	3.654	.084	.311	.8766	.25436	3.594
Skewness	−2.646	−1.684	.578	−2.646	−1.795	−0.874	−2.684	0.374
Kurtosis	8.685	5.765	2.987	6.565	4.656	5.678	5.956	3.679
lnEFP	1.000							
lnFD	.212∗	1.000						
t-Statistic	2.757	–						
lnNRR	.654∗	.289∗	1.000					
t-Statistic	12.675	4.756	–					
lnZGLO	.367∗	.612∗	.321∗	1.000				
t-Statistic	5.476	12.746	4.796	–				
lnNREC	.521∗∗	−.364∗∗	0.637∗	−0.553∗	1.000			
t-Statistic	3.575	−3.756	8.686	−8.907	–			
lnREC	.525∗	.311∗	.212∗∗	.611∗	−.533∗	1.000		
t-Statistic	8.678	4.897	3.686	11.685	−7.785	–		
lnFD∗lnZGLO	.321∗	.643∗	.385∗	.656∗	−0.542∗	0.622∗	1.000	
t-Statistic	2.685	17.9576	2.8567	12.8567	−3.6895	8.6636	–	
lnNRR∗lnREC	.764∗	.302∗	.711∗	0.511∗	.122∗	.611∗	0.421∗	1.000
t-Statistic	12.563	5.786	11.764	8.858	3.9577	11.656	7.0846	–

*Analysis factors in natural log are presented in **Table 1** with their descriptive and inferential statistics and association matrixes shown below. As has been said, **Table 1** shows that the empirical evidence for all factors is based on average, mean average, max, lowest variance, deviation, and other tests. lnEFP, lnFD, lnNRR, lnGLO, lnNREC, lnREC, lnFDlnZGLO, and lnNRRlnREC are all potential factors with average scores of 1.2153, 4.3832, 1.8401, 6.5583, 4.3312, 1.9431, 10.9415, and .1029, respectively.*

TABLE 2 | Chow Test for structural stability.

Dependent variable = ln CO_{2it}	[1]
Variable	
$lnCO_{2it-1}$	.8256***(.2576)
$Lngdp_{It-1}$	−.0032 (.0423)
D_t	−.2137 (.4658)
D_t*$lnCO_{2it-1}$	.0503 (.0522)
D_t*$lnGDP_{it-1}$	.0441 (.0711)
Cons	−.1144*(.3122)
Country fixed effects	YES
N	711
Adjusted R2	87.55%
F-test for joint null hypothesis	
(a) $D_t = 0$	
(b)D_t*$lnCO_{2it-1} = 0$	
(c) D_t*$lnGDP_{it-1} = 0$	
1st Period Observation (1985–1999)	411
2nd Period Observation (2000–2011)	397
Structural Change Tests	
Chow Test (F test)	F (3,783) = 3.21 [.0041]
Wald Test (Chi Square Test)	8.7755 [.0085]
LM Test (Chi Square Test)	8.7685 [.0091]

TABLE 3 | Summary statistics.

Variable	Mean value	
	1990–1998	2001–2012
$lnCO_{2it}$	−2.31	−1.55
$lnGDP_{it}$	7.12	7.08
$lnURB_{it}$	4.45	4.98
$lnTR_{it}$	5.00	5.15
$lnDC_{it}$	3.56	3.78
$lnLLQ_{it}$	3.05	4.03
$lnPC_{it}$	3.09	3.89
IQ_{it}	0.58	0.41
$POLITY2_{it}$	−2.55	3.98

4 RESULTS AND DISCUSSION

4.1 Empirical Result for Chow Test

As a result of the Chow test, we were able to identify a fundamental transformation in 1999. Dioxide emissions in United states have grown dramatically over the last decade, and this year was chosen as a break point because of this trend, according to the theory (Stulz, 1996). **Table 3** briefly explains summary of the Statistical analysis carried out in this study. Due to these considerations, we divide the sample into distinct time intervals $T_1 = 1990 - 1999$ and $T_2 = 2000 - 2011$. Chow tests for $T_1 = 1990 - 1999$ and $T_2 = 2000 - 2011$ are substantially distinct; the F test rejects the null hypothesis for both eras at the 1% level of significance. As a result, we may infer that the calculated value in time is meaningfully distinct from. As a result, the Chow test shows that Dioxide emissions from 2001 to 2012 underwent a rapid transition that was significantly more pronounced than the one from 1990 to 1998. As a result, we change the study period from 2001 to 2012.

4.2 Results for Cross Country Regression

To account for nation fixed effects in our cross-country regressions, we partition the dataset into two stages. As a result, our systems' capacity to assign probabilities is improved, and regression estimates are free of bias and heterogeneity bias (Mima and Hallett, 1999).

TABLE 4 | Cross Country regression.

Dependent variable: ln CO_{2it}						
Variable	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
$lnGDP_{it-1}$	0.6913***(.1078)	0.6978***(.1148)	1.0206***(.1243)	1.0232***(.1243)	.7958***(.1323)	.8234***(.1425)
$lnURB_{it}$	0.5978**(.2135)	0.6087***(.2189)	0.0078 (.2376)	0.2132 (.2567)	.4879*(.2456)	.5129**(.2328)
$lnTR_{it}$	.0784 (.2470)	.0411 (.2438)	−.0511 (.2725)	−0.0944 (.2567)	.0906 (.2569)	.0079 (.2321)
$lnDC_{it}$	.4988***(.0965)	.4987***(.1274)	—	—	—	—
$lnLLQ_{it}$	—	—	.7566 (.6169)	0.8976***(0.1978)	—	—
lnPCit	—	—	—	—	.2389 (0.3987)	.4122***(.1678)
IQ_{it}	.0511 (0.6955)	—	−1.6654 (4.7786)	—	−.1324 (3.8750)	—
$POLITY2_{it}$	—	.0007 (.5976)	—	.1866 (0.1978)	—	.0321 (.0622)
$lnDC_{it}*IQ_{it}$	.0021 (0.0017)	—	—	—	—	—
$lnDC_{it}*POLITY2_{it}$	—	.0039 (0.0199)	—	—	—	—
$lnLLQ_{it}*IQ_{it}$	—	—	.7122 (2.5632)	—	—	—
$lnLLQ_{it}$*POLITY2it	—	—	—	−.0402 (.0605)	—	—
$lnPC_{it}*IQ_{it}$	—	—	—	—	.3978 (.8976)	—
$lnPC_{it}*POLITY2_{it}$	—	—	—	—	—	.0012 (.0332)
Cons	−8.7886***(.8765)	−8.6658***(.8977)	−12.6698***(3.6659)	−10.6753***(2.6596)	−8.7809***(2.6687)	−8.7869***(.7809)
Country Fixed Effect	YES	YES	YES	YES	YES	YES
N	44	44	41	43	42	44
Adjusted R2	86.44%	86.44%	83.76%	86.45%	86.44%	86.09%

Tables 4–6 *demonstrate the cross-county regression relationships between variables.*

TABLE 5 | Environment kuznets curve (EKC).

Dependent variable: ln CO_{2it}						
Variable	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
$lnGDP_{it-1}$	.6913***(.1078)	.6978***(.1148)	1.0206***(.1243)	1.0232***(.1243)	0.7958***(.1323)	0.8234***(.1425)
$lnURB_{it}$	.5978**(.2135)	.6087***(.2189)	0.0078 (.2376)	0.2132 (.2567)	0.4879*(.2456)	0.5129**(.2328)
$lnTR_{it}$	.0784 (.2470)	0.0411 (.2438)	−0.0511 (.2725)	−0.0944 (.2567)	0.0906 (.2569)	0.0079 (.2321)
$lnDC_{it}$	.4988***(0.0965)	.4987***(.1274)	—	—	—	—
$lnLLQ_{it}$	—	—	.7566 (.6169)	.8976***(.1978)	–	—
lnPCit	—	—	—	—	.2389 (.3987)	.4122***(.1678)
IQ_{it}	.0511 (0.6955)	—	−1.6654 (4.7786)	—	−.1324 (3.8750)	—
$POLITY2_{it}$	—	.0007 (.5976)	—	.1866 (.1978)	—	.0321 (.0622)
$lnDC_{it}*IQ_{it}$	.0021 (.0017)	—	—	—	—	—
$lnDC_{it}*POLITY2_{it}$	—	.0039 (.0199)	—	—	—	—
$lnLLQ_{it}*IQ_{it}$	—	—	.7122 (2.5632)	–	—	—
$lnLLQ_{it}$*POLITY2it	—	—	—	−.0402 (.0605)	—	—
$lnPC_{it}*IQ_{it}$	—	—	—	—	.3978 (.8976)	—
$lnPC_{it}*POLITY2_{it}$	—	—	—	—	—	.0012 (.0332)
Cons	−8.7886***(.8765)	−8.6658***(.8977)	−12.6698***(3.6659)	−10.6753***(2.6596)	−8.7809***(2.6687)	−8.7869***(.7809)
Country Fixed Effect	YES	YES	YES	YES	YES	YES
N	44	44	41	43	42	44
Adjusted R2	86.44%	86.44%	83.76%	86.45%	86.44%	86.09%

Table 5 shows the following information. Strong positive and significant Gross domestic product correlations may be found everywhere. From .6913 to 1.0232, they're in the ballpark. Economic development and Carbon dioxide emission seem to be tightly linked, as seen by this finding. It is a mixed bag when it comes to trade and urbanization. When the sociocultural context is taken into account, financial intermediation and cash equivalents have a significant impact. In all economies, though, internal lending to the corporate companies is considerable. Lastly, eliminating organizational performance indicators will seem to have very little effect on Pollutant emissions, despite the fact that their incorporation enhanced the model's fit. As a result, many nations have not yet met the necessary threshold for macroeconomic variable to provide a positive and measurable influence on Carbon dioxide emission. We are really pleased with the adjusted R-square in all of our simulations, which shows that our model has an excellent ability to accurately forecast the dataset.

As shown in **Table 6** (which includes the square component of GDP), gross domestic product, financial sector development, and urbanization all play a significant role in determining carbon dioxide emissions. In all equations, the squared component of gross domestic product is small, which shows that there is no EKC. GMM modelling is thus based on economic output and macroeconomic variable indices as well as urbanization and carbon dioxide emissions. There is a pressing requirement to examine the stationarity and integration order of the relevant variables after assessing the potential

TABLE 6 | Unit root tests results.

Series	Level			First Difference			Order of Integration
	CADF		CIPS	CADF		CIPS	I (1)
lnEFP	−2.674		−1.675	−3.786*		−4.096*	I (1)
lnFD	−2.449		−1.546	−4.896*		−3.789*	I (1)
lnNRR	−1.667		−3.885	−3.756*		−2.596*	I (1)
lnZGLO	−1.495		−2.785	−4.967**		−3.797*	I (1)
lnNREC	−1.634		−2.757	−3.775*		−3.686*	I (1)
lnREC	−2.875		−1.968	−3.509*		−4.795*	I (1)
lnFD*lnZGLO	−2.586		−1.633	-4.756*		−2.576*	I (1)
lnNRR*lnREC	−2.553		−1.678	−3.882*		−3.957*	I (1)
Critical Values	1%	5%	10%	1%	5%	10%	
	−2.48	−2.26	−2.17	−2.39	−2.22	−2.11	

TABLE 7 | GMM estimates.

Dependent variable = ln CO_{2it}

Variables	GMM [1]	GMM [2]	GMM [3]
$lnCO_{2it-1}$	.7611***(.0884)	.7433***(.0813)	.7433***(.0811)
$lnGDP_{it-1}$	.1978***(.0812)	.2356***(.0805)	.2218***(.0803)
$lnURB_{it-1}$	.0923 (.1427)	.0911 (.0612)	.0811 (.1422)
$lnDC_{it-1}$	0.0421 (0.0301)	—	—
$lnLLQ_{it-1}$	—	0.0877 (.0602)	—
$lnPC_{it-1}$	—	—	0.0112 (.01827)
Cons	−1.532***(.6987)	−1.4894***(.7065)	−1.7844***(.6089)
Year2002	−.0389 (.0411)	.0422 (.0412)	−.0389 (.0367)
Year2003	−.0611 (.0441)	.0071 (.0422)	−.0711*(.0422)
Year2004	−.0081 (.0351)	.0621 (.0376)	−.0155 (.0342)
Year2005	−.0143 (.0443)	.0443 (.0351)	−.0287 (.0322)
Year2006	−.0298 (0.0361)	.0281 (.0422)	−.0367 (.0321)
Year2007	−.0387 (0.0354)	.1431 (.0341)	−.0511 (.0331)
Year2008	−.0182 (0.0332)	.0411 (.0342)	−.0229 (.0321)
Year2009	−.0389 (0.0411)	.0089 (.0278)	−.0421 (.0298)
Year2010	−.0522 (0.0412)	.0154 (.0308)	−.0684*(.0388)
Year2011	+	+	+
Year2012	−.0411 (.0301)	.0472 (.0303)	−.0384 (.0277)
Sargan Test of Overidentification	[.2498]	[.2087]	[.1749]
N	276	273	275

CSD throughout cross-sections. The present research performs two s-generation panel stationary tests based on this perspective (i.e., hereafter CADF and CIPS). As shown in **Table 7**, the results of panel unit root testing are summarized. A look at **Table 5** reveals that, despite the fact that all of the parameter combinations have unit root problems at the level, all of them are really static following the initial differences in I (1) modification. Using this method, it is possible to determine whether long-term cointegration occurs or not.

4.3 Results for Generalized Method of Moments Estimator

The positive and substantial lag in carbon dioxide emission correlation shows that the present level of carbon dioxide emission is heavily influenced by its previous levels. Secondly, environmental costs are linked to gross domestic product per capita in a significant way. To put it another way, as GDP per capita rises, so do emissions of carbon dioxide. From .02088 to .02351, the statistic is consistent. Emissions of carbon dioxide, on the other hand, have no relevant correlation with urbanization and banking sector development metrics. **Table 7** shows GMM estimates.

The bottom panel diagnoses The GMM estimates all cleared the Sargan overidentification test. A non-significant *p*-value indicates that almost all the instrumentation is legitimate. The year's dummy estimations were weak. Long-run results by elasticity has been explained precisely in **Table 8**. The regressions did not provide a year dummy for 2001. So the change in CO_2 emissions between 2001 and the later years was not considerable. As the most important predictor of greenhouse gas emissions, we next analyses the short and long-run elasticity of demand for gross domestic product per capita.

4.4 Results for Long-Run Elasticity Estimates

Table 8 lists the long-run AMG and CCE-MG coefficients and elasticity estimates. These three estimating methods yield the same

TABLE 8 | Results of long-run elasticity.

Variable	Model 1: EFP = f (FD, NRR, ZGLO, NREC, REC)				Model 2: EFP = f (FD, NRR, ZGLO, NREC, REC, lnFD*lnZGLO)				Model 3: EFP = f (FD, NRR, ZGLO, NREC, REC, lnNRR*lnREC)			
	AMG		CCE-MG		AMG		CCE-MG		AMG		CCE-MG	
	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value	Coeff	*p*-value
lnFD	.231*	.000	.218*	.000	.321**	.020	.369***	.084	.278*	.001	.452*	.004
lnNRR	.278**	.049	.358*	.004	.423**	.024	.745**	.010	.166*	.000	.156**	.021
lnZGLO	−.618*	.001	−.566**	0.016	−0.251*	.000	−.145*	.005	−.151***	.092	−.156***	.061
lnNREC	.163***	.087	.017***	0.052	0.132***	.080	.002	.489	.147**	.044	.029	.131
lnREC	−.141**	.013	−.161*	0.007	−0.391*	.005	−.676***	.054	−.223**	.026	−.598*	.000
lnFD*lnZGLO	—		—		−.722**	.032	−.559*	.001	—		—	
lnNRR*lnREC	—		—		—		—		−0.876*	.001	−2.7845*	.001
Constant	5.875**	.019	5.8760*	0.001	10.218*	.007	16.843*	.000	−8.575*	.000	−14.7853*	.000
Wald χ^2	60.786*	.000	89.56*	0.000	151.678*	.000	89.686*	.000	16.894*	.000	26.684*	.000
RMSE	.0285	.0269	.0341	.026	.027	.0311						

coefficient sign but vary in quantity and significance level. Apart from globalization, the conversion factor of the parameters predicted by AMG is smaller than those predicted by CCE-MG. Due to its factors which determine the accuracy, the variable may be understated or exaggerated. Furthermore, this work used both cross-country regression and GMM estimators as benchmarks, with the CCE-MG method being used to test robustness. Both methods give consistent results despite cross-sectional dependence and slope variation.

According to the AMG estimating technique, nations with a measure of financial development have a considerable contribution to environmental degradation, increasing it by .231 percent over time. Models 2 and 3 also support these results. The nation's economic banking market is responsible for promoting the cost of labour (capital), and this advanced financial infrastructure disburses financial assets to local firms, which in turn leads to greater amounts of hazardous waste and the combustion of more atmospheric CO_2. The fact that industrialized countries are putting more money into micro and major manufacturing facilities is also encouraging. Financiers might use this opportunity to increase funding for new enterprises, such as paying lower or environmental mitigation. Because of this, the monetary service's growth and the consequent increase in environmental pollution are both under the thumb of the capitalized consequences. Another possible reason may be that the banking sector's growth may have increased the spending power of consumers by offering low-interest loans. Air conditioners, cars, and industrial spaces, which put a significant strain on the environment, are made more accessible to customers in this way. For this reason, the world's most technologically advanced nations should take a strong stance against the banking sector's impact on the environment. It is consistent with (Li et al., 2010; Shiogai et al., 2010; Faes et al., 2014). This contradicts previous studies that found that the established financial sector of an economy reduces environmental harm in ASEAN and 15 severely polluted nations, accordingly, based on the results of (Dempster, 1967; Kroll and Stedinger, 1998).

It is clear that the use of natural resources has a substantial impact on the environment. A 1% increase in natural resources would increase the ecological deficit by .3021 percent over time in resource-rich nations. This is consistent with the findings of Models 2 and 3 (with interaction terms). This shows that the depletion of natural resources is the primary cause of increased harm to the environment in these nations. Earlier studies on Pakistan (Basu and Srinivas, 2015) and China (Douglas et al., 2000) support these conclusions as well. According to (Kjeldsen and Jones, 2007; Rahman et al., 2020), the use of natural resources has a considerable impact on environmental performance. The results of this analysis, on the other hand, contradict those studies. Because of their richness in natural resources, these economies are often predicted to gain foreign currency. Natural resources have a helpful function in enhancing economic pollution if they are well managed and used in a well-organized manner. The local environment decreases and the rate of natural resource depletion speeds up. As a result, natural resources may be redeveloped. This shift from old equipment that relied on land and resources to greener equipment (technology) that incorporates inventiveness, repurposing, continuous improvement, remanufacturing, and synthetic resources has occurred throughout the globalization age. Natural resource extraction has a positive impact on economic growth and environmental degradation, which is why this is justified (El-Jabi and Turkkan, 2016).

According to empirical evidence, these countries' entire ecosystems have been reduced dramatically over the long term, contrary to what was predicted above. If all other factors remain constant, one percent of a globalization effect reduces environmental deterioration by .6249 percent, according to Hardy. Models 2 and 3 also support these results. These nations might benefit from the relocation of parts of their commercial transactions to other nations, thus reducing the emission of carbon dioxide and depleting their natural resources *via* increased FDI and trade openness. (Griffis and Stedinger, 2007; Castellarinet al., 2008) are in disagreement with the present study's results. The environmental footprint is positively affected by the results of the use of non-renewable energy. For every 1% increase in non-renewable energy usage, there is a .1561% increase in the impact on the planet. Non-renewable energy has been linked to environmental damage in these countries, as evidenced by the findings of (Kjeldsen and Jones, 2009); the high demand for traditional energy resources in these (developed) countries goes hand-in-hand with their high offshore

economic activity, which will contribute immensely to the success of an environmental collision. According to the studies, using renewable energy has a significant negative impact on the environment. This demonstrates how renewable energy sources have a lower environmental impact than fossil fuels. In the long run, a 1% increase in renewable energy use reduces carbon emissions by .1386 percent. There is a consistent pattern of sustainable and non-renewable energy use in all models (either with or without interaction effects). That renewable energy technology is being developed and used is evidence that these countries are on the correct track to meet the Sustainable Development Goals (SDGs). (Zrinji and Burn, 1994; Ouarda et al., 2001; Neves and Gomes, 2011) find similar results.

AMG and CCE-MG results with estimated coefficients are shown in **Table 5**. (in **Table 5**, Models 2 and 3). Models 2 and 3 now include both interaction components, and all of the correlations are in the same direction as they were in Model 1. The coefficient of lnFDlnZGLO is positively accurate with the opposite sign (= .7198 and p .05) in Model 2, where we incorporate the interaction of capital formation with globalisation (lnFDlnZGLO). When this interaction variable is included, financial integration has an even more significant impact on the ecological footprint in Model 2 than in Model 1. There is evidence to suggest that the integration of globalisation has a positive impact on developed nations' financial systems, which in turn boosts the amount of money being invested in more environmentally friendly and effective technology. This is due to the fact that these countries are economically developed and have a broad perspective as a result. When these nations' financial sectors are nearing their optimum level, they spend their assets in third world countries *via* FDI, where the pollution halo concept dominates, which in turn reduces emissions, particularly during globalization mode. This is another argument. Increasing financial resources and constructing additional environmental pollution mitigation institutions are a must for these nations!

5 CONCLUSION AND POLICY IMPLICATIONS

The current study measure the combining effects of economic development and globalization towards energy efficiency and environmental degradation in 32 developing countries by using data from 1990 to 2018. The findings show that panel data has undergone a structural shift Rom 1990 to 2016, the Chow test has shown that the amount of carbon dioxide emissions has been steadily increasing, whereas the rate from 2000 to 2011 has been steadily decreasing. According to cross-country regressions, environmental problems in the 32 developed countries are heavily influenced by factors such as economic growth, urbanization, and banking sector development, while the consequences have little impact on air quality. It is evident that financial development and ecological degradation are linked in a strong and consistent way after accounting for possible endogeneity, structural breakdowns, and simultaneity bias. Financial advancement, increasing energy use, and urbanization procedures have led to a rise in the exploitation and use of natural resources in the 32 developed countries of today. According to experts, one of the most important aspects of reducing greenhouse gas emissions is a shift toward renewable energy. As a result, from 1990 to 2016, this research examines the ecological impact of the ten most economically developed nations' use of energy sources—non-renewable energy and renewable energy. While globalization and renewable energy use reduce environmental pollution in this area, financial growth, ecological systems and nonrenewable energy usage increase the CO_2 emission level. A selected macroeconomic function is beneficial to environmental deterioration in a second model that includes the interplay between economic development in the developing world and environmental regulators. According to this study, financial institutions in these nations have an important function as mediator variables of globalization in addition to protecting sustainability practices.

Finally, in the third model, we incorporate a natural resource-based moderator. The findings suggest that air quality can be controlled more effectively when both factors are taken into consideration. So, the findings of this study on economic development, energy, natural resources, and the environment are essential because of the two interaction factors. The cross-country regression test results reveal a bidirectional causation correlation between corporate development, non-renewables, and renewable sources, as well as environmental consequences, natural resources, solar and wind, and banking sector development.

(i) Even so, there is a one-way causality link between natural resources and ecological footprint, between contribution to global warming and globalizations, between globalizations and stock market development, between direct investment and non-renewables, and eventually between globalizations, non-renewables, and renewables, in conserving natural resources. In light of the above observational assumptions and econometric results, this paper proposes a number of policy recommendations that are compatible with these findings. It is imperative that the banking system be restructured in resource-rich nations since financial growth has been linked to a decrease in sustainability practices. Furthermore, it is necessary to provide additional financing for investments in the manufacturing sector that is better than the majority of non-renewable energy use. The environmental contamination in this area may be mitigated by ensuring that clean financing options are available.

(ii) These countries have a large supply of capital that is used domestically and sometimes earns money that is transferred from these countries. Natural resource rents have a favorable effect on the impact on the planet because of the volatility in the use of these resources. Oil and gas, hydrocarbons and coal may be reduced while renewable energy sources like producing energy and waves can be bolstered in these nations' policymaking and governance. The utilization of renewable energy sources has the potential to reduce pollution, promote long-term productivity expansion, and keep the environment safe. In order to protect their species, these governments must allocate these funds for rejuvenation.

(iii) By balancing producers and consumers to prevent the natural depletion of natural resources, policymakers should ensure that research, training, innovation, safety, conferences, workshops, R&D, expenditure on skills courses, and sustainable development are maintained.

(iv) Playmakers and economy-wide bodies should also concentrate on policies relating to the elimination of tariffs, immigration tariffs, as well as taxation and promoting FDI in resource-rich nations since globalizations has been shown to minimize pollution. For the sake of globalization's environmental quality, trade and FDI in traditional technologies should be prohibited. To speed up globalizations, an expanded role for economic quality is required. As a result of this, economic growth initiatives should also focus on the amount of trash that is generated. It is possible to acquire the necessary experience and abilities to manage trash throughout globalizations. The only viable answer to this problem is to increase the use of renewable energy sources, given the detrimental implications of climate change resources and non-renewable energy use on environmental stewardship. Renewable energy sources are the only long-term solution to environmental degradation and energy potential vulnerabilities; hence they must be prioritized in the post-COVID-19 period.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Energy Security and Energy Poverty in Emerging Economies: A Step Towards Sustainable Energy Efficiency

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This paper presents the energy security, energy poverty, and mediating role of environmental tax policy. The environmental tax policy affects energy consumption and energy poverty. The research applied multiple, comprehensive, and relevant sets of indicators to measure energy security, energy poverty, and environmental consideration of energy poverty through environmental tax. The study used a mathematical composite indicator and an econometric estimation to conduct an empirical estimation. The study used annual data from 1990 to 2018 and concluded that long-run associations between energy security, energy poverty, and environmental tax have been characterized by the linear and asymmetric association to specify hidden cointegration behavior among the trilemma. The results show how policymakers have clouded the decision to implement appropriate energy security to mitigate energy poverty in Vietnam through environmental tax.Results show that from 2001 to 2016 in Vietnam, energy security was low and energy poverty was high, but after 2016, it can be seen that there is a dramatic change in energy security and energy poverty. The year 2018 shows the highest energy security index score (0.92) and the lowest energy poverty index score (0.12). Since 2017, Vietnam's rural electrification plan has provided electricity to 100% of Vietnam's population. The plan provides electricity access to 82 million people who traditionally have no grid access.

Keywords: energy, economic, social indicator, environment sustainability, composite index, G7 countries

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INTRODUCTION

To explore the capacity for growth, the estimation of energy resources and operational costs is of interest to scientific scholars in Vietnam, indicating that the country has the capacity to grow wind power intensely. Vietnam has the economic potential to grow green energies, as Nong et al.(2019) have also indicated. The future production of wind power in Vietnam was again verified by Nguyen et al. (2021). On the other hand, de Faria et al. (2017) defined the capacity for hydropower production and energy policies of climate change in neighboring countries. Wu et al. (2021) suggested that non-hydro power operational costs have recently declined, but are still higher than hydropower costs. In the following paragraphs, more comprehensive information on energy supplies is given.

There have been more energy studies conducted in Vietnam since 2000, but there are still minimal outputs. Similar and wider subjects related to electricity have been explored in these studies. At the very beginning of the 21st century, researchers debated a lot on markets and technology for solar energy, waste management, growth strategies for electricity, and energy poverty (Abbas et al., 2020; Khokhar et al., 2020; Liu Z. et al., 2021). The Kuznets environmental curve hypothesis, and the reliability and effect of emerging co-fired biomass technology, among others. In Vietnam, there are also a few study articles on energy policies. Hoang et al. (2022), for example, examined energy strategies in Vietnam but omitted an overview of the country's natural resources and related research. In their report, Zimmer et al.(2015) only checked energy management and recycling policies. Truong et al.(2017) recently studied Vietnam's energy policies by applying the framework of various parameters for decision-making but omitted a study of the country's energy supplies and related research.

The impact of this manuscript lies in various dimensions such as (i) an empirical estimation associated with the relationship of energy security, energy poverty, and mediating role of environmental tax policy. The environmental tax policy affects energy consumption and energy poverty. The study used a mathematical composite indicator and an econometric estimation to conduct an empirical estimation. The study used annual data from 1990 to 2018 and concluded that long-run associations between energy security, energy poverty, and environmental tax have been characterized by asymmetric and linear association to specify unseen cointegration behavior. (ii) We developed the composite index of energy poverty and energy security by using multiple, relevant, and comprehensive sets of factors, through geometric mathematical combined indicator, and (iii) unlike others, we incorporated the mediating role of an environmental tax on energy consumption, which significantly affects the energy poverty. The study holistically contains the national energy portfolio including utilization of coal capacity to produce electricity and its environmental consequences, and finally, (iv) we proposed a novel policy framework for government and policymakers to combat energy economic and environmental considerations in the country. To the best of the author's knowledge, it is a unique form of the initial empirical analyses to view the energy sector transformations to improve energy security and to alleviate energy poverty to ensure long-term economic advancement along with environment-friendly mechanisms.

DATA AND METHODOLOGY

System of Indicators

There are no systematic assessments and analytical evaluations of energy resource science, pertinent policies, and independent academic research studies to ensure that these components are properly connected and challenges are identified so that the country can transition quickly to a low-carbon and cleaner economy (Abbas et al., 2021; Liu H. et al., 2021; Khoso et al., 2021). Investments in power plants are also inspired by private, non-governmental enterprises and international investors. In Vietnam, there are reportedly 73 independent power plants, distributed through hydro, coal, oil, gas, and renewable sources. One business in the United States (AEZ Corporation) provides the largest foreign-invested plant with the financing of $2.1 billion with a plant capability of 1,240 MW (Wu et al., 2021). Many feed-in tariffs (FITs) are also provided by the government to attract investors in the clean energy market. Retail rates, however, are still controlled by the government (Gao et al., 2020; Hou and Xu 2020; Li 2020). Furthermore, a tariff with minimum rates for people and maximum rates for businesses is imposed at the same time throughout the country; however, product availability and price settings remain fully regulated by the government. These challenges create difficulties in estimating the actual costs of the electricity industry, thus lowering energy production and thereby impacting the economy as a whole. **Table 1** presents the indicator selection for energy poverty and energy security.

To counter the important danger of ecological degradation and energy disaster, the international community battles to solve the issue of energy security without harming the environment. Therefore, the indicators of energy, economic, and environmental performance evaluate the effects of energy. In the next paragraphs, the indicators are explained in detail.

Energy self-sufficiency ratio

Nations reliant on imported energy are vulnerable to energy and climate since their economy is strongly dependent on price fluctuations and the economic growth may weaken due to interruption in the energy market (Greene 2010; Löschel et al., 2010).

Diversification index

The energy imports and their costs mean that the country is efficient in diversifying its assets (APERC 2007; Tapia et al., 2016; Wang et al., 2018). Composite country risk factors have been added in the diversification index of energy dependency.

Energy consumption

Energy consumption measures sufficient energy supply for human welfare (Cohen et al., 2011). Energy consumption is affected by economic development, population, energy structure, technological progress, industrial structure, urbanization, and industrialization level (Yousaf et al., 2020; Tehreem et al., 2020; Wasif Rasheed and Anser 2017; Xu et al., 2020). Economist groups encourage increasing energy consumption while environmentalists discourage higher energy consumption, mediate between these two lobbies, reduce energy consumption, and do not negatively affect the economy; the latest energy policies strongly bet on energy efficiency (Martinez and Ebenhack 2008). Countries at different economic development stages are considerably intended towards different energy sources while energy consumption is also considered as a mutually agreed upon consensus and as a cost-type indicator (Cohen et al., 2011; Sovacool and Mukherjee 2011; Ang et al., 2015).

TABLE 1 | Indicator selection for energy poverty and energy security.

Dimension	Indicators	Unit
Energy poverty		
	Access to electricity	(% of the population)
	Alternative and nuclear energy	(% of total energy use)
	Electric power consumption	(kWh per capita)
	Non-poverty incidence	
	Poverty headcount ratio	
	Renewable electricity output	(% of total electricity output)
	Poverty headcount ratio at $1.90 a day	(2011 PPP) (% of the population)
Energy security	Renewable energy consumption	(% of total final energy consumption)
	Time required to get electricity	Days
	Access to clean fuels and technologies for cooking	(% of the population)
	The energy intensity level of primary energy	(MJ/$2011 PPP GDP)
	Energy imports, net	(% of energy use)
	Energy use	(kg of oil equivalent per capita)
	Fossil fuel energy consumption	(% of total)
	Energy self-sufficiency	
Environmental tax	Tax on petrol	(kWh per capita)
	Tax on diesel	
	Tax on gas	
Control variables	R&D	(Current US$)
	Line losses	-
	Gini Index	(% of R&D)
	R&D in renewable	
	Energy intensity	

Renewable Energy

The energy sector is the largest contributor to CO_2 emissions (Yuan et al., 2008). Fuel usage (Filipović et al., 2015) is taken as a renewable energy indicator based on the share of renewable energy within the total electricity production in the national energy mix.

DEA-Like Mathematical Composite Indicator

Once the indicator framework has been constructed, the next critical step is using mathematical composite indicators. Technologically, combined indicators are economics, society, and the environment (Moon and Min 2017). Composite indicators (CI) can be applied to equate different countries in measuring national-level energy performance and carbon emission to provide valuable information to policymakers in global negotiations. Different stakeholders, scholars, politicians, and neighborhood leaders can communicate their sets of principles and priorities during the development of CIs, which should be focused on a participatory and negotiating method. Since separate participants' principles and priorities can be in dispute or synergistic, establishing the philosophical structure for CIs is a negotiating procedure. When it comes to macroeconomics, CIs equate the outputs of various items, which are referred to as specific spatial units, but when it comes to metropolitan and regional planning, these may be different (regions, states, districts, and census zones) (Song et al., 2013). Construction of CIs may be focused on spatial details and depends on geographic information systems and spatial statistics research, as well as statistical databases, depending on their regional preference, although the MCDA method has been rigorously criticized because of its subjectivity of assigning weights to indicators. This question is addressed by Zhou et al.(2006) by expanding a DEA-like model, which holds the properties of balanced combination that can be designed as below:

$$\begin{aligned} gS_j &= \max \prod_{k=1}^{n} x_{jk}^{gw_k} \\ s.t. \prod_{k=1}^{n} x_{jk}^{gw_k} &\le e, \quad j = 1, 2, \ldots, m \\ gw_k &\ge 0, \quad k = 1, 2, \ldots, n \end{aligned} \tag{1}$$

$$\begin{aligned} bS_j &= \min \prod_{k=1}^{n} x_{jk}^{bw_k} \\ s.t. \prod_{k=1}^{n} x_{jk}^{bw_k} &\ge e, \quad j = 1, 2, \ldots, m \\ bw_k &\ge 0, \quad k = 1, 2, \ldots, n \end{aligned} \tag{2}$$

Contrary to **Eq. 9**, Eq. **10** allocates the worst set of weights to underlying indicators or sub-indicators. bS_j shows the worst score of country j and bw_k shows the worst set of weights.

$$\begin{aligned} gS_j^{'} &= \max \sum_{k=1}^{n} gw_k \, x_{jk}^{'} \\ s.t. \sum_{k=1}^{n} gw_k x_{jk}^{'} &\le 1, \quad j = 1, 2, \ldots, m \\ gw_k &\ge 0, \quad k = 1, 2, \ldots, n \end{aligned} \tag{3}$$

$$\begin{aligned} bS_j^{'} &= \min \sum_{k=1}^{n} bw_k x_{jk}^{'} \\ s.t. \sum_{k=1}^{n} bw_k x_{jk}^{'} &\ge 1, \quad j = 1, 2, \ldots, m \\ bw_k &\ge 0, \quad k = 1, 2, \ldots, n \end{aligned} \tag{4}$$

where $x_{jk}^{'} = \ln(x_{jk}^{'})$, $gS_j^{'} = \ln(gS_j)$, $bS_j^{'} = \ln(bS_j)$.

$$ESESI_j(\lambda) = \lambda \cdot \frac{gS_j^{'} - gS_{\min}^{'}}{gS_{\max}^{'} - gS_{\min}^{'}} + (1-\lambda) \cdot \frac{bS_j^{'} - bS_{\min}^{'}}{bS_{\max}^{'} - bS_{\min}^{'}} \tag{5}$$

where $gS'_j = \ln(gS_j), bS'_j = \ln(bS_j), gS'_{\overline{\max}} \max\{gS'_j,\ j = 1, 2, \ldots, m\}$, $gS'_{\overline{\min}} \min\{gS'_j,\ j = 1, 2, \ldots, m\}$, $bS'_{\overline{\max}} \max\{bS'_j,\ j = 1, 2, \ldots, m\}$, $bS'_{\overline{\min}} \min\{bS'_j,\ j = 1, 2, \ldots, m\}$, and $0 \le \lambda \le 1$ is an adjusting and control parameter. Model (13) is a min–max linear scaling model within [0,1] through the value of λ. If decision-makers have no exact preferred choice, the all-underlying indicators needed λ = 0.5. At the same time, the C_i S.I. becomes a normalized description of gS_i if $\lambda = 1$, and it becomes a normalized description of b S_i if $\lambda = 0$. Due to the virtue of, model (13) produces more surrounding C.S, which can easily handle constructing indices. C S_i satisfies the following enviable characteristics: (i) CI is unit invariant, (ii) 0 < CI ≤ 1, and (iii) C I_i is invariant with respect to the right-hand side of the constraints in models (16) and (17). Property of point 1 translates in constraints of models (11) and (12); if we replace one with any other values, the C.S. will not be changed.

You can either ignore any weight (zero) or assign overweight or underweight, which is problematic. We have not placed any restrictions on the selection of weights for underlying indicators because weights possess the property of flexibility in their assignment. Sub-indicators may be ignored when a total is calculated in these cases. The weight restriction is a common practice in the construction of the composite index to ensure that each indicator contributes to the aggregation purpose. As a result, the following are the maximum weights for each sub-indicator:

$$L_k \le \frac{w_k x'_{jk}}{\sum_{k=1}^{n} w_k x'_{jk}} \le U_k, \quad k = 1, 2, \ldots, n \tag{6}$$

Where L_k and U_k show the allocated $L_k = 0.05$ and $U_k = 0.20$, which shows that energy security and energy poverty index lie in the range from 5% to 20%. Different dimensions of worth may, in effect, be at odds with one another and be of concern to different social classes. As a consequence, various evaluation instruments will spread "costs" and "benefits" across groups in different ways and with different spatial and temporal trends. This is largely dictated by the amount of compensation across values permitted by appraisal instruments and, therefore, by the sustainability model used.

Econometric Estimation

The impact of the multidimensional variables on energy poverty can be evaluated through numerous variables. These socioeconomic variables are given in **Table 1**. Due to the variety and diversity in the underlying variables, it is possible to produce a comprehensive index of energy poverty. A multifaceted and comprehensive energy poverty index facilitates rigorous analysis to ease the development of a policy framework (Hoff 2007). Maximal likelihood estimations were performed in STATA using a Tobit model to determine how significant each parameter was. For truncated data, the Tobit model has been used to assess the strength of the association between the dependent and independent variables. The multidimensional energy poverty index is a dependent variable, whereas the set of variables in **Table 1** is taken as independent in this study. The values of the MDEPI interval are between [01]: 0 being the lowest deprivation score, which specifies no energy poverty in any dimension, and 1 indicating the greatest energy poverty score in all dimensions. As a result, a two-limit Tobit regression technique is used in order to perform a more accurate analysis of the data:

$$\begin{aligned} Y^*_{it} &= \beta x_{it} + U_{it} \\ Y_{it} &= \{Y^*_{it} - if - Y^*_{it} \ge 0\} \\ &\quad 0\, otherwsie \end{aligned} \tag{7}$$

where Y^*_{it} is a latent dependent variable that has been used in the study characterized by it being dual censored through the upper limit 1 and lower limit 0. u_{it} shows the distributive error term, i signifies the observations, t shows the time period, and x_{it} shows the set of explanatory indicators for the constructed framework. β shows the vector for the parameter of a coefficient. Any shortened observation can be characterized through MDEPI = $\{i\colon Y^*_{it} \le 0 \cap Y^*_{it} \ge 1\}$.

RESULTS AND DISCUSSION

Individual Indicator Score

To be specific, power is supplied to the EVN by all electricity suppliers, to provide electricity to homes, factories, and institutes funded by the national government. In the future energy market, they are also encouraged to make further spending. International and private funding is leveraged in the form of construction-operating-transfer contracts performed by foreign and private firms to construct power plants to operate for several periods of time before being sold to the Vietnamese government. The government aims to significantly expand the network in all regions of the world by 2030 with a view of accompanying increased electricity generation [87].

Table 2 presents the targets of electricity generation. Energy services are at the center of the industrial growth of the Vietnamese economy. Energy production prices, on the one hand, add greatly to the national income and the energy market provides multiple job opportunities in both urban and rural areas. Simultaneously, in nearly all contemporary industrial development processes, transport, and domestic operations, energy is an indispensable part. Therefore, energy-related policies are still considered a major concern by the Vietnamese government, as unforeseen economic, to improve the national energy stability (energy supply). That is, from being completely state-controlled to business-oriented, the energy market has been changed. This transition culminated in the efficiency of resource utilization on both the supply and demand sides, thus leading to energy efficiency improvements. The mechanism has steadily improved, though, and the government still dominates the energy markets to a large degree.

There are only such sectors where private and international investment is readily accepted. The private sector, for example, is especially encouraged to participate in the sale of petroleum products to end users. By 2017, there were 14,000 gasoline stations in total, of which instead, in September 2008, eventually transforming them into a price discovery on the open market.Consequently, retail rates are also fixed and

TABLE 2 | Targets for electricity generation.

	2020 target		2030 target	
	Capacity installation MW (%)	Output level Billion kWh (%)	Capacity installation MW (%)	Output level Billion kWh (%)
Total	75,000 (100%)	330 (100%)	146,800 (100%)	695 (100%)
Hydropower	19,125 (25.5%)	64.68 (19.6%)	23,048 (15.7%)	64.64 (9.3%)
Coal-fired	36,000 (48%)	154.44 (46.8%)	75,749 (51.6%)	391.98 (56%)
Gas-fired	12,375 (16.5%)	79.2 (24%)	17,322 (11.8%)	100.08 (14.4%)
Renewables	4,200 (5.6%)	14.85 (4.5%)	13,799 (9.4%)	41.7 (6%)
Wind power	1,000 (1.3%)	2.31 (0.7%)	6,200 (4.2%)	16.68 (2.4%)
Solar power	4,200 (3.6%)	10.56 (3.2%)	5,579 (3.8%)	17.38 (2.5%)
Biomass-fired	500 (0.7%)	1.98 (0.6%)	2000 (1.4%)	7.65 (1.1%)
Nuclear power	975 (1.3%)	6.93 (2.1%)	9,689 (6.6%)	70.2 (10.1%)
Imported	2,325 (3.1%)	9.9 (3%)	7,193 (4.9%)	26.41 (3.8%)
b) Targets for electricity transmission (additional construction)				
	2011–2015	2016–2020	2021–2025	2026–2030
500 kV station (MVA)	17,100	26,750	24,400	20,400
200 kV station (MVA)	35,863	39,063	42,775	53,250
500 KV line (km)	3,833	4,539	2,234	2,724
200 kV line (km)	10,637	5,305	5,552	5,020
	2011–2020		2021–2030	
Investment	$48.8 billion (100%)	$75 billion (100%)		
Power plants	$32.5 billion (66.6%)	$49.1 billion (65.5%)		
Transmission and distribution	$16.3 billion (33.4%)	$25.9 billion (34.5%)		

irregularly modified by the government. They are regulated at small amounts and all recommended price increases must be accepted by the government. Carbon price proposals were also provided by the Vietnamese government. There is a market stability fund under these measures, receiving those funds from every gasoline liter sold. In order to control market costs, finances are used to pay back to vendors in the event of high price changes. However, the shortfall of the fund still runs, so importers often face negative margins, since costs are not permitted to rise significantly in line with higher oil prices in the foreign market.

Aside from that, the Vietnam Rural Electrification Project, which started in 1998, played a major role in Vietnam's electrification in the 1990s. This initiative alone has supported 82 million more people with energy connections. To improve access, the initiative used a community development strategy, concentrating on funding, social support, and public buy-ins.

Via tailored curriculum design, the program was able to achieve societal buy-in and interest for these initiatives. The program's effectiveness hinged on city citizens being equipped to support authorities in preparation and implementation so that the framework could better represent the neighborhood it was designed to benefit. In a related way, the program introduced the service agent paradigm for project management. Locals were taught how to conduct routine technological and commercial activities, as well as routine maintenance, utilizing this tool. This not only lowers the running costs of the power grid, but also employs local people, ensures a quicker reaction to crises, and encourages greater control by regional communities of the electricity infrastructure. Any process of the initiative was planned to provide neighborhood engagement. The policy has been remarkably effective in increasing access as a consequence of this architecture, and it is a big factor why Vietnam has achieved 100% electrification in such a short period of time.

Vietnam's electrification route is unique in that it relies heavily on hydropower, but the policies and projects implemented by the country can be applied to other countries without access to electricity. In Vietnam, the shared planning and government expenditure that will allow the electrification project to begin, as well as the local contribution in implementing and using various sources of financing, will be a model for other countries. Developing countries, such as Kenya, Angola, and Chad, will copy Vietnam's electrification programmed by utilizing sustainable energy that is already available in the country's regions. The world is eager to expand global access to electricity after seeing such a strong case for the importance of electrification in improving quality of life and other aspects of growth, such as education and healthcare.

Table 3 displays clear installed capacity and production level goals for every energy source, as well as the electricity grid network focuses and investments expected by 2030. Furthermore, 377,000 and 231,000 more rural households were anticipated by the government.

Table 4 shows the targets for electricity generation. Results show that from 2001 to 2016 in Vietnam, energy security was low and energy poverty was high, but after 2016, it can be seen that there is a dramatic change in energy security and energy poverty. The year 2018 shows the highest energy security index score (0.92) and the lowest energy poverty index score (0.12). Vietnam's rapid and complete electrification is a remarkable achievement that has provided electricity to all parts of the country, including rural electrification. Since 2017, Vietnam's rural electrification plan has provided electricity to 100% of Vietnam's population. The plan provides electricity access to 82 million people who

TABLE 3 | Energy security and energy poverty analysis results of Vietnam.

Year	Energy security	Energy poverty
2001	0.71	0.27
2002	0.65	0.39
2003	0.62	0.37
2004	0.65	0.35
2005	0.57	0.37
2006	0.66	0.38
2007	0.64	0.39
2008	0.71	0.36
2009	0.69	0.42
2010	0.67	0.42
2011	0.61	0.39
2012	0.58	0.34
2013	0.63	0.28
2014	0.69	0.26
2015	0.72	0.24
2016	0.78	0.18
2017	0.92	0.13
2018	0.93	0.12

traditionally have no grid access. Vietnam has made great strides in attaining growth targets by achieving electrification to provide high-quality medical care and improve overall welfare. In other regions, electricity consumption is not widespread.

In the past, for four major reasons, the Vietnamese government has been highly focused on the construction of hydropower plants. First, water supplies are readily accessible worldwide. Second, due to the low population at the time, per capita water supplies were comparatively high. A third factor in the growth of electricity production has been the increase in demand for electricity at home (Iqbal et al., 2019). Fourth, dam building also has many advantages, not only for producing power, but also for preventing flooding, regulating drainage, transporting water, as well as providing jobs and income sources to many people. Over time, several new power plants have also been designed to promote industrial growth with rising energy demands. Today, with a capacity of 2,400 MW, Son La Dam is a major dam in Vietnam and Southeast Asia, constructed between 2005 and 2012.

There is a comparatively limited installation capacity for the proposed programs. This is because of the global and cultural consequences and limitations. For example, compensation policies for displaced residents were vague and unfavorable when the Hoa Binh Dam was built. Furthermore, environmental and socially harmful effects have not been addressed in particular [60]. Before passing the National Assembly, were postponed and updated several times.

Coal Supplies and Power Plants Fueled by Coal

For Vietnam's economic growth, coal is an essential energy resource. It is mostly used in Vietnam for the firing of power plants, cement, and steel processing. The Vietnam National Mineral and Coal Industries Group (Vinacomin), founded in 1994, conducts the extraction and processing of coal in Vietnam. From the quantity of coal output to the retail rates, the company regulates all facets of coal mining firms. Vina Comin creates quotas for mining each year and has proposals for sale rates based primarily on manufacture expenses. There are presently 52 coal sources in the country, mostly in the northeastern province of Quang Ninh. Most coal deposits, however, are situated underneath the Red River Basin, extending from Hanoi (the capital of the country) to the Thai Binh province over a wide area of 3,500 km^2. The extraction would be exceedingly difficult and expensive. Furthermore, the mining of coal causes high levels of contamination.

There were 36 million tons of coal produced in 2018, but that number is expected to rise steadily to 58 million tons in 2019, 90 million tons in 2025, and 130 million tons in 2030 due largely to an increase in the requirement for power production in the United States. This would definitely raise the burden due to barriers to domestic production, creating instability in prices to cause unsustainable growth of the coal sector and power generation operations. In selected times, **Table 5** displays the primary energy supply and demand in Vietnam. There has been a surplus of coal production in Vietnam over the past decade. Demand for coal has been relatively strong in the domestic market in current years, primarily for the production of electricity.

In the first 6 months of 2019, Vietnam's coal imports rose by 108% in contrast to the same period in 2018. Indonesia, Australia,

TABLE 4 | Targets for electricity generation.

Hydropower plants	Capacity (MW)	Electricity output per year (billion kWh)	Year of operation
Son La	2,400	10	2012
Hoa Binh	1,920	8.16	1994
Lai Chau	1,200	4.7	2016
Yaly	720	3.7	1996
Huoi Quan	520	2.8	2013
Tri An	400	1.7	1991
Na Hang (Tuyen Quang)	342	1.3	2008
Ham Thuan - Da Mi	300	1.55	2001
Trung Son	260	1	2017
Ba Ha	220	0.83	2008
Thac Mo	225	0.8	1995 (extension, 2017)
Thac Ba	108	0.4	1971

TABLE 5 | Vietnamese primary energy supply and demand from 2005 to 2015 (KTOE).

Resources	2005	2010	2011	2013	2014	2015
Production						
Coal	19,457.52	25,138.92	26,624.04	23,444.70	23,457.96	23,695.62
Crude oil	19,279.02	15,571.32	15,798.78	17,379.78	18,094.80	19,503.42
Gas	6,328.08	8,482.32	7,711.20	8,692.44	9,306.48	9,742.02
Hydropower	1,441.26	2,416.38	3,589.38	4,994.94	5,248.92	4,923.54
Non-commercial biomass energy	15,157.20	14,167.80	14,285.10	13,942.38	12,999.90	12,163.50
Total	61,662.06	65,777.76	68,008.50	68,454.24	69,108.06	70,028.10
Demand						
Coal	8,543.52	15,024.60	15,917.10	17,583.78	20,356.14	25,100.16
Crude oil	12,515.40	17,667.42	16,373.04	14,991.96	18,054.00	19,930.80
Gas	5,006.16	8,482.32	7,711.20	8,692.44	9,306.48	9,742.02
Hydropower	1,441.26	2,416.38	3,589.38	4,557.36	5,248.92	4,923.54
Non-commercial biomass energy	15,089.88	14,167.80	14,285.10	13,946.46	12,999.90	12,163.50
Total	42,596.22	57,758.52	57,876.84	59,773.02	65,966.46	71,861.04

Russia, and China are the major coal suppliers for Vietnam [69], plans to expand the ability of coal-fired energy generation. Most of the plants currently working are in the north, where the bulk of coal supplies are in storage and extensive activities are carried out. Due to abundant coal supplies, they targeted development in this region. About ten biomass and coal-fired power stations exist in Vietnam. However, the overall power (approximately 480 MW) is comparatively limited and the performance is not high. Vietnam has been a significant manufacturer of crude oil in Southeast Asia for decades. Vietnam is reportedly projected to produce 320,000 barrels per day, steadily declining from the 2004 high of 403,000 barrels per day. Owing to the complexities of exploitation in deep water fields, production is also likely to decline in the future. Investment has also been discouraged by lower oil prices since 2014, further placing strain on output levels.

At the end of 2016, natural gas stocks were projected to be approximately 24.7 trillion cubic feet (Tcf), up from 6.8 Tcf in 2011. Approximately 50% of these reserves were in deep water, which comprises high CO_2 emissions, in the northern region of the Red River basin. This results in high investment prices, as well as the high cost of development. Vietnam has recently generated about 375 billion cubic feet per year, which, without imports from overseas markets, is adequate for domestic demand. Only in southern Vietnam are oil- and gas-fired power plants built. All 14 operational power plants have an overall capability of 8,700 MW. In the coming decade, about 20 power plants are also planned for construction to increase overall volume to about 19,000 MW by 2030. Economic growth values lie between 2.56 and 0.73. The USA has the highest value of 2.56, while Italy has the minimum economic growth of 0.73.

Measures to Protect the Environment

In 2015, at the Paris Climate Change Summit, Vietnam publicly pledged itself to reducing the country's carbon levels. In other terms, Vietnam committed to reduce the level of GHG emissions by 8% compared to business as normal by 2030, subject to a 25% target upon receipt of foreign financial assistance for the introduction of innovative technology. The Environmental Conservation Act was issued by the Vietnamese government in 2005. This Act mandated all agencies, households, and individuals and addressed all facets of the preservation of the atmospheric properties; however, no tax was levied on the amount of electricity or pollution in the Act. The Vietnamese National Assembly also added tax thresholds on environmental development to the Environmental Conservation Bill in 2010. These tax rates have been imposed on many polluting goods, starting on January 1, 2012 (**Table 6**). The legislation contained multiple sets of tax rates for each item, and no higher tax rates relative to the highest amounts for each group would be allowed to be set by the government. However, new tax rates were recently approved by the National Assembly to raise taxes through 30%–50%. It was anticipated that these taxes would decrease pollution levels and lower usage levels for users of particularly environmentally damaging goods. These tax thresholds are also projected to raise consumers' perception of environmentally damaging goods, thus improving environmental safety.

The National Power Master Plan Program is also in danger of not meeting its installed capacity and performance level goals due to technology and expenditure cost restrictions and domestic supply of clean energy. Such goals are incredibly expensive and potentially difficult to reach in the near future. The production of electricity is therefore heavily dependent on foreign prices and prevailing supply policies, and the power industries in Vietnam may not fulfill their capital demands for generating operations, resulting in limitations in the achievement of invested capability and production levels. Because of the lack of financial resources and technology, the country was forced to rely heavily on developing fossil fuel-fired electricity, which would lead to a longer transformation process into a renewable and carbon economy of production. Therefore, there is a need for more funding from foreign organizations and governments concerning technology transition, along with economic development.

Econometric Estimation

At the country level, an energy poverty index measures how much of a burden it is for people to have access to adequate energy sources. **Table 8** presents the OLS and Tobit regression outcomes. The results of Tobit and OLS regression are

TABLE 6 | Results of tax thresholds.

Product (1)	Unit (2)	Tax rate in 2012 (VND)	Tax rate in 2012 (US$) ($1 = 23,000 VND)	Tax rate in 2019 (VND)	Tax rate in 2019 (US$) ($1 = 23,000 VND)
		(3)	(4)	(5)	(6)
Gasoline, oil, grease	liter	1,000–5,000	0.05–0.19	5,000	0.19
Gasoline, except ethanol	liter	1,000–4,000	0.05–0.15	4,000	0.15
Oil aircraft	liter	500–3,000	0.02–0.11	3,000	0.11
Diesel oil	liter	500–3,000	0.03–0.10	2,000	0.05
Petroleum	liter	400–4,000	0.02–0.12	3,000	0.12
Lubricants	kg	600–3,000	0.02–0.13	4,000	0.13
Grease					
Coal	ton	20,000–40,000	0.5–2.1	20,000	0.76
Lignite	ton	30,000–50,000	0.6–2.3	25,000	2.4
Anthracite coal	ton	25,000–45,000	0.5–2.7	35,000	0.78
Fat coal	ton	20,000–40,000	0.6–2.3	30,000	0.86
Other coal	ton	2,000–7,000	0.04–0.22	5,000	0.22
Hydrogen-chlorofluorocarbon liquor	ton	40,000–60,000	2.4–1.23	60,000	3.26
Taxable-plastic bag	ton	1,000–3,000	0.03–0.13	1,000	0.04
Constrained herbicide	ton	2000–4,000	0.06–0.27	2,000	0.06
Constrained pesticide	kg	1,500–5,000	0.06–0.23	1,500	0.07
Constrained forest product preservative	kg	2,000–5,000	0.05–0.23	2,000	0.05

TABLE 7 | Main estimation results of Dependent Variable Energy self-sufficiency.

	OLS	Tobit
	EPI	EPI
EPI_lag1	0.177[c]	0.197[b]
	(0.031)	(0.035)
E_Security	–0.055[b]	–0.035[c]
	(0.01)	(0.013)
E_Security_Lag1	–0.034[b]	–0.0255[c]
	(0.01)	(0.013)
Env_Tax	–0.033[c]	–0.073[c]
	(0.057)	(0.037)
R&D	–0.0331[c]	0.055[c]
	(0.075)	(0.055)
Line losses	0.025[b]	0.0371[c]
	(0.035)	(0.053)
Gini	–0.077[b]	–0.0307[c]
	(0.03)	(0.017)
Renewable	–0.015[b]	–0.015[c]
	(0.010)	(0.011)
E_imports	–0.331[c]	–0.533[c]
	(0.077)	(0.051)
R&D in Renewable	–0.071[b]	-0.057[c]
	(0.037)	(0.037)
Non-poverty incidence	–0.077[c]	-0.033[b]
	(0.03)	(0.011)
Adjusted R^2	0.075	
Log-likelihood		159.0946

Note: p-*value in brackets and standard errors in parentheses.*
[a]p < *0.1.*
[b]p < *0.5.*
[c]p < *0.01.*

presented in **Table 7**, as well as the regression analysis for the variables under study with two different models. It is observed that lagged energy poverty coefficients are statistically positive and significant at 1% significance level, showing that the present energy poverty is affected by the performance of previous periods of energy poverty in Vietnam. It is further observed that the coefficient of both energy security and lagged term of energy security is 0.055 and 0.0255, respectively. Energy poverty and its lag term are statistically negative above 5% significance level.

Control Variable Analysis

The estimates show that the control variable results are in line with the expectations of this study (**Table 7**). These findings show the impact on energy poverty of all the control variables except for line losses. Environmental tax (Env Tax) is further observed to have negative and statistically significant effects on energy poverty with coefficients (0.033) and a negative correlation with poverty (0.073). Environmental taxes discourage excessive energy consumption, which does not help the environment. One percent significance means that the negative correlation between R&D coefficient and energy poverty is statistically significant. It shows that a 1% increase in R&D can reduce the percentage by 3.31%–5.5%. Even at a significant level of 1%, line losses in both models have an impact on energy poverty that is both positive and significant. The level of energy poverty rises by 2.5% to 3.71% with a 1% increase in line losses. The Vietnamese government needed to take decisive action to reverse the line's decline.

The Gini index coefficient is statistically negative and significant at 5% or higher level. All living things and human production are carried by the land, as stated by Jin et al. (2018). Furthermore, the estimation result for the independent variables' renewable energy is found to be statistically significant and negative at a least level of 5%. This is overwhelming. It is clear that the green economic growth phenomenon has undergone a fundamental shift. Governments are compelled by this widespread practice to abandon environmental laws and regulations, which leads to further environmental degradation. Vietnam's energy poverty is measured using this index. Environmental taxes were also assessed as a further indicator.

TABLE 8 | Moderating effect of Tobit regression results.

Variable	Tobit regression	
	EPI	EPI
EPI	0.133***	−0.033**
	(0.031)	(0.035)
E_Security	−0.055**	
	(0.01)	
E_Security_lag1		−0.035***
		(0.013)
E_Security*Env Tax	−0.033**	
	(0.053)	
E_security_lag1*Env_tax		−0.033***
		(0.033)
R&D	−0.331***	−0.331***
	(0.035)	(0.033)
Line losses	0.055**	0.035
	(0.035)	(0.053)
Gini	0.033***	0.033***
	(0.03)	(0.013)
Renewable	0.015	−0.015*
	(0.010)	(0.011)
E_imports	−0.331***	−0.533***
	(0.033)	(0.051)
R&D_in_Renewable	−0.031**	−0.053***
	(0.033)	(0.033)
Non_Poverty_incidence	−0.033***	−0.033**
	(0.03)	(0.011)
	(0.033)	(0.013)
P_o	−0.015	−0.013*
	(0.013)	(0.011)
Gini Index	(0.33)	(0.311)
Log-likelihood	155.1046	156.237

Moderating Effect

The moderating effect of environmental taxes on energy poverty is measured through cross term of environmental taxes (**Table 8**). All the results of the moderating effect of environmental taxes are significantly negative at above 5% significant level. It indicates that the moderating effect is somewhat existent for energy poverty. The result of the regression estimation shows that more taxes can discourage the excessive use of energy that can help to mitigate the energy poverty level.

Sensitivity Analysis

To ensure the robust results in **Table 9**, the uncertainty factors in Vietnam can be reduced. Although the uncertainty could while construction of composite index score measurement individual indicators performance score. In order to settle the sensitivity analysis, we have generated the new dataset [± 10%] from the original dataset.

TABLE 9 | Sensitivity analysis of composite index score.

Year	Energy security	Energy poverty	Std. Dev
2001	0.73	0.31	0.03
2002	0.65	0.37	0.04
2003	0.68	0.37	0.04
2004	0.65	0.35	0.03
2005	0.62	0.37	0.04
2006	0.64	0.38	0.03
2007	0.64	0.39	0.03
2008	0.74	0.36	0.03
2009	0.69	0.44	0.04
2010	0.68	0.42	0.03
2011	0.61	0.39	0.01
2012	0.58	0.34	0.03
2013	0.63	0.28	0.04
2014	0.69	0.26	0.05
2015	0.72	0.24	0.04
2016	0.82	0.19	0.06
2017	0.91	0.15	0.04
2018	0.92	0.14	0.03

DISCUSSION

Wind farms can also be built in Vietnam, particularly along the coast and in the south. A total of 31,000 km^2 of inland land was predicted to be suitable for the deployment of wind power in 870 km^2 of land that could produce electricity at a cost of less than $0.06 per kWh (Hou and Xu, 2020). In contrast, the entire 99-MW wind power facility has the largest wind power facility, while the other plants have a capability of less than 40 MW. In these two countries, there are also several other wind power projects under construction. In general, under the current Power Production Plan (Iqbal et al., 2019; Mohsin et al., 2021b; Iqbal S et al., 2021).

Due to the growing need for energy for industrial development and population growth, Vietnam has been considering the use of nuclear power plants since 1995. By 1995, electricity demand was expected to exceed 100 billion kWh 20 years later; the construction of renewable energy through 2030 was perceived in a revision published in 2007. In the country, several plants were built to provide construction sites, and a capacity of 10,700 MW by 2030 was targeted for nuclear power plants. It was agreed upon in a 2016 study to build 4,600 MW of capacity by 2030. However, in 2016, the Vietnamese National Assembly agreed to repeatedly delay the building of nuclear power plants after several consultations and projections, particularly after studying the Fukushima tragedy in Japan, due primarily to reduced estimates of demand and increases in prices.

Economic and energy markets in Vietnam are currently undergoing a transition to a new economy as a result of the country's rapid growth. An in-depth examination of all aspects of the energy supply, industries, policies, and science studies is therefore required to help this growing economy achieve sustainable growth and a better manufacturing climate. However, the market for renewable energy generation in Vietnam is still small and lacking in financial resources and cutting-edge technology. Because of this, the country needs to create fossil fuel-fired electricity, specifically coal-fired electricity, in the short and medium term while developing renewable energy. It is known that, in the short term, this would lead to higher pollution levels that are in contrast with the overall goals of energy policies. Such a blended production of energy supplies will also lead to achieving Paris Agreement goals, to which the country has dedicated itself. In addition, Vietnam has not published a clear direction or central agenda to help the country meet its dedicated goals (Mohsin et al., 2021a). The Vietnamese government is currently tightly

regulating its energy prices, and this process contributes to inefficient distribution of capital and decreased appeal for investment. Furthermore, the FIT policies are not stable enough to draw investments to grow green energy. The network is currently crowded in certain areas, suggesting high risks for investors, which may lead to a failure to meet the planned deployed capacity and production volume goals. High power growth goals, which are highly dependent on imported energy, would also result in significant instability and challenge to the achievements of Vietnam due to structural and policy shifts in overseas markets. Better and better-informed energy conservation strategies would benefit Vietnam as they can be the secret to meeting the country's lower-cost goals and reducing pollution levels. In order to provide better technology to sustain such growth, the country also had to reinforce its human capital and research operations.

The digital economy, on the other hand, has never been studied as a determinant of technical progress. There is a lack of studies on the interaction between the digital economy and technical progress. This thesis bridges a void in the literature by using digitization as a novel explanatory variable. The beginnings of digitalization in the economy can be traced back to the internet's arrival in the 1990s, which changed the commercial and industrial systems (Asbahi et al., 2019; Rao et al., 2022). The usage of digital technology in the economy has evolved over time, particularly after the arrival of the fourth industrial revolution. The concepts "economic automation" and "artificial intelligence" apply to emerging technology that have changed the function and efficiency of the economy and industries. The word "digitalization" in economics relates to innovative digital technology that assists in growing the productivity of social development in Vietnam as Vietnam is a developing economy. Ideas, information, imagination, and invention are the pillars of the modern economy. Countries all over the world are utilizing digitalization to change their economies. However, the invention of digital technologies takes a long time, as does the time it takes to get it to market. Furthermore, in the advancement of emerging technology, there is a major communication lag between countries. Due to technical advances in industries and organizations, manufacturing and production in Vietnam have risen significantly in the modern age. Advances in information and communication technology (ICTs), the internet of things, and multimedia platforms have altered the market environment. Furthermore, these advances have had a major effect on institutional efficiency and organizational structure. In terms of growth, societal transformation, and industrial progress, the progress of digitalization in the economy has helped national economies like Vietnam.

CONCLUSION AND POLICY IMPLICATION

The study used a mathematical composite indicator and an econometric estimation to conduct an empirical estimation. The study used annual data from 1990 to 2018 and concluded that long-run relationships between energy security, energy poverty, and environmental tax have been characterized by the linear and asymmetric association to specify hidden cointegration behavior among the trilemma. The results show how policymakers have clouded the decision to adopt suitable energy security to mitigate energy poverty in Vietnam through environmental tax. Results show that from 2001 to 2016 in Vietnam, energy security was low and energy poverty was high, but after 2016, it can be seen that there is a dramatic change in energy security and energy poverty. The year 2018 shows the highest energy security index score (0.92) and the lowest energy poverty index score (0.12). Since 2017, Vietnam's rural electrification plan has provided electricity to 100% of Vietnam's population. The plan provides electricity access to 82 million people who traditionally have no grid access.

Long-run energy policy effects of shifts in oil prices (*via* environmental tax) were also derived carbon free economy while increases in oil prices are found to have major effects on oil consumption (with a cumulative elasticity of 5.7.1% increase in the price of oil contributing to a 5.7% combined and asymptotic decrease in oil consumption). The total influence of energy security on energy poverty mediated by environmental tax is economically and statistically important as oil prices that strongly affect the overall energy portfolio grow by 12.3% with a 1% rise in the price of oil.

Energy security and energy poverty index. As the media and information technologies have grown increasingly, the awareness of people and businesses about climate change has also changed. This advancement also helps the activities of other countries and individuals in many other regions around the world. Moreover, sales standards have been increasing to allow more people to access the internet. Furthermore, the Suit strategy is not stable, and is often particularly risky for investors. Official challenges often create substantial difficulties in obtaining alternative sources of loans. Furthermore, lower government-regulated power rates often hinder investment in renewable energy. A detailed knowledge of these considerations will serve to provide informed guidance on effective policy and shift a nation to a carbon-free and prosperous economy. Our analysis has some shortcomings that can be fixed in future studies. First, due to a lack of evidence, this analysis does not recognize the environmental implications of various types of biomass energy production. Second, our analysis looks at the effect of biomass energy output on the Vietnam environmental footprint, which contains seven developing economies. Future studies may expand on this work by looking at the environmental influence of biomass energy development in developed or emerging economies, thus strengthening our understanding of the biomass energy–ecological footprint nexus.

First and foremost, energy demand in the Asia Pacific region is expected to double by 2030, as approximately a billion people presently live without permit to electricity in emerging APEC nations. More than 130b individuals are "energy poor" in Southeast Asia alone, suggesting nearly no approach to electricity and other energy sources for them. This is the first challenge for policymakers to establish a clear long-term energy plan for their nations to tackle energy poverty: policymakers are highly motivated by short-termism, or political myopia, in the

battle against energy poverty by exploiting, encouraging, and subsidizing fossil fuels and managing differences between energy demand and supply. Unfortunately, in developed countries like Vietnam, this short-termism has come to be accepted as a big tool in the armory of socio-economic policies with unforeseen environmental effects in developing countries (Iqbal W et al., 2021).

The trilemma of energy policy is an unlikely or contradictory trinity: a nation must at most select two out of three: (i) short-term energy protection through the utilization of inexpensive energy supplies; (ii) environmental mitigation through the elimination of energy-related CO_2 emissions; (iii) long-term diversification of the energy portfolio to alternative sources such as renewables. In order to produce and perpetuate energy policy inertia, we find that the above trilemma can become a behavioral policy pit. Policymaking will discourage this policy inertia from sufficiently diversifying the energy portfolio with important human security ramifications across the globe. In other words, our approach aims to discover why there is inertia in energy policy and what induces it. Once policymakers have a foreknowledge of the exact centers of policy inertia, it will be possible to develop suitable policies to combat the underinvestment issue in order to diversify the energy portfolio.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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How Government Corruption and Market Segmentation Affect Green Total Factor Energy Efficiency in the Post-COVID-19 Era: Evidence From China

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Energy and environmental pollution have attracted wide attention, but few studies have been conducted on green total factor energy efficiency (GTFEE) from the perspective of government corruption and market segmentation. By using the panel data of 30 provinces in China for the period 2006 to 2017, this paper tests the relationship between government corruption, market segmentation, and GTFEE. Moreover, considering the threshold effect of government corruption and market segmentation on GTFEE, the system generalized method of moments and the dynamic threshold panel model are adopted to analyze the nonlinear relationship. The regression results indicate that government corruption significantly decreases GTFEE, and market segmentation also has a significant negative impact on GTFEE. Moreover, market segmentation exacerbates the negative impact of corruption on GTFEE. The more serious the government corruption, the more severe the inhibitory effect of market segmentation on GTFEE. Similarly, the higher degree of market segmentation can increase the restraining effect of corruption on GTFEE. The results are still valid after a series of robustness tests. This paper suggests that countries should adopt severe anti-corruption actions, speed up the process of regional integration, and provide a good institutional environment support for the improvement of GTFEE.

Keywords: corruption, market segmentation, post-COVID-19 era, China, energy efficiency

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INTRODUCTION

Since the 21st century, China's economy has achieved remarkable achievements (Abbasi et al., 2022; Fang et al., 2022), which continue to grow despite the unexpected COVID-19 pandemic in 2020 (Razzaq et al., 2020; Iqbal et al., 2021; Yang et al., 2021; Ahmad et al., 2022; Wen et al., 2022). The GDP in China has reached 101.6 trillion yuan in 2020, with an annual growth rate of 2.3% (Irfan et al., 2021a; Lee, 2021). However, with the rapid economic growth, China's energy demand is increasing year by year (Hao et al., 2021a), the problems of energy consumption and pollutant emissions have become increasingly prominent (Elavarasan et al., 2021a; Elavarasan et al., 2021b; Khan et al., 2021; Ren et al., 2021a; Islam et al., 2022). According to Statistical Review of World Energy, China's consumption of primary energy attained 145.46 exajoules, accounting for 26.1% of the world. China's CO_2 emissions in 2020 are 9,899.3 million tons, accounting for 30.7% of the world's total, making it the world's largest carbon emitter. It is worth noting that China's economic

growth is inseparable from the extensive use of fossil energy in the short term (Hao et al., 2021b; Rauf et al., 2021). To smooth the energy and environmental dilemma, the nation has made a lot of measures in terms of energy-saving and emission reduction and has solemnly promised to achieve carbon peaking by 2030 and carbon neutrality by 2060 (Wu et al., 2021b; Zhang et al., 2021). Improving green total factor energy efficiency helps reduce pollution emissions and energy consumption, and that is the only way to protect the ecological environment and achieve economic growth (Wu et al., 2021a; Ren et al., 2022; Lee et al., 2022).

Environmental pollution is a public product with strong negative externalities (Irfan et al., 2020; Varadarajan, 2020; Irfan and Ahmad, 2022; Irfan et al., 2022; Nuvvula et al., 2022). To reduce the harm of pollution to residents' health, governments around the world have paid more attention to environmental governance and formulated corresponding environmental policies to improve environmental quality (Ahmad et al., 2021; Razzaq et al., 2021; Elavarasan et al., 2022a; Elavarasan et al., 2022b). However, under the economic growth "championship" among governments, local governments may relax environmental regulations and acquiesce in local polluting enterprises to discharge excessive pollutants (Ali et al., 2021; Tanveer et al., 2021; Shi et al., 2022; Xiang et al., 2022). Moreover, to obtain more resources and seek political protection, firms tend to induce local governments to erect barriers and protect businesses within their jurisdiction from other external competition through bribery tactics (Park et al., 2006). It makes enterprises lack enthusiasm for improving energy efficiency, resulting in great differences in the effects of environmental policies across countries (Hao et al., 2020; Pei et al., 2021). Therefore, energy efficiency is closely related to the effect of policy implementation. Once there is serious rent-seeking and corruption in policy implementation, it will directly affect the policy effect and energy efficiency (Ren et al., 2021a). Based on the corruption perceptions index 2021 issued by the non-governmental organizations (NGO) Transparency International, China ranks 66 out of 180 countries with a score of 45, which is higher than the average score of 43, showing that China has a severe corruption problem. However, the relationship between government corruption and energy efficiency still lacks systematic research. Moreover, few scholars study the influence of corruption on GTFEE from the view of market segmentation. Although market segmentation preserves local enterprises and markets from the competition, it prevents the free flow of factors between different regions, resulting in the misallocation of factor resources, which is not favorable to technological innovation and the enhancement of energy efficiency (Hao et al., 2020; Irfan et al., 2021b; Guo and Liu, 2022).

This paper aims to analyze the following questions. What is the influence of government corruption and market segmentation on GTFEE, respectively? Does market segmentation affect the effect of government corruption on GTFEE? Is there a threshold effect in the influence of government corruption and market segmentation on GTFEE? However, existing studies have not addressed these issues. Three variables are incorporated into the same research system to solve the above questions. It is not only useful for understanding the relationship between corruption, market segmentation, and GTFEE but also provides a reference for other developing countries to formulate anti-corruption policies and improve GTFEE policies. Overall, the innovation of this study has three main points. First, this paper brings corruption, market segmentation, and GTFEE into the same analytical framework to better understand the relationship between the three perspectives. Second, this paper examines the influence of corruption on GTFEE, market segmentation on GTFEE, and market segmentation as moderating effects. Third, this study addresses the endogeneity problem by establishing a dynamic threshold model, which separately studies the nonlinear relationship between corruption and GTFEE at different market segmentation levels.

LITERATURE REVIEW

The Influence of Corruption

Corruption is an important issue that countries have to deal with. There are many different interpretations of corruption, which vary by time and place, such as bribery, extortion, nepotism (Rose-Ackerman and Palifka, 2016; Mungiu-Pippidi, 2019). From the perspective of economic, corruption is mainly about government corruption or official corruption, which abuses public power for private interests (Rose-Ackerman, 2017; Igiebor, 2019). From a macro perspective, in the existing literature, there are two different opinions on the impact of government corruption on economic development. One view is that corruption distorts public resource allocation, inhibits economic and social development, reduces social welfare, and weakens capital accumulation (Liu and Mikesell, 2014; Dimant and Tosato, 2018). Cieślik and Goczek (2018) found that the interactions of corruption and investment had a significantly negative inhibition of economic development. Swaleheen (2011) analyzed the impact of corruption on the growth rate of per capita income and concluded that corruption had an inhibition effect. However, some studies have the view that corruption makes up for the shortcomings of the market mechanism, and the rent-seeking behavior of enterprises reduces the government's inefficient control, which is beneficial to economic development, that is, corruption is a "lubricant" (Ren et al., 2021a; Gunter, 2021). Acemoglu and Verdier (1998) believed that allowing some corruption was conducive to the realization of an ideal state, which could reduce corruption, increase investment and effectively allocate talents.

Furthermore, from a micro perspective, the production and development of enterprises require a lot of capital, which induces enterprises to choose rent-seeking behavior to seek financial support. Getting better rewards through rent-seeking makes entrepreneurs spend more time paying bribes than operating, researching, and innovating, which can lead to distorted talent allocation and slow down innovation in the long-run (Dincer, 2019; Chen, 2021). In addition, Djankov et al. (2002) conducted a study on the degree of regulation in running enterprises in 85 countries found that corruption protects inefficient enterprises,

hindered the entry of new enterprises, and disrupts the effective competition order of the market. De Rosa et al. (2010) believed that corruption couldn't help companies reduce the time to deal with bureaucratic procedures and hindered the improvement of corporate productivity. However, some studies disagree. Lui (1985) proposed a formal queuing model and found that the opportunity cost of queueing people was disparate, which leaded people with high time value to pay a certain amount of bribe cost to "jump the queue" and finally achieved "Pareto optimality". The auction model established by Beck and Maher (1986) also had a similar logic. In auction behavior, corruption improved the efficiency of resource allocation by directly assigning auction items to the most efficient enterprise. Ren et al. (2022) found that the system quality distinguished the influence of corruption on total factor productivity. In a high-quality system, corruption hinders the improvement of total factor productivity. However, in countries with institutional defects, corruption supports productivity growth and is beneficial (Aidt, 2009).

Literature of Market Segmentation

With economic development, market segmentation has attracted widespread attention. Young (2000) found that China's reform model enabled governments to interfere in the market through administrative power and implemented local protection. Contrary to the principle of giving play to regional comparative advantages, local governments allocate scarce resources to industries with high returns, intensifying market segmentation. However, Fan and Wei (2006) extended Young (2000) with a more comprehensive dataset and more rigorous econometric method to test the law of one price and found that the price distinction between different cities in China narrowed over time, converging to the law of one price. They also found that China's "gradualist" reform was conducive to promoting regional market integration. The current research on market segmentation measurement method mainly includes the production method (Young, 2000), the price method (Parsley and Wei, 1996), the trading method (Naughton, 2003; Poncet, 2003), and the specialization index method. Poncet (2005) drew on the gravity model and boundary effects to calculate market segmentation and tests the effect of inter-provincial trade barriers on market segmentation by using China's inter-provincial trade data. Parsley and Wei (1996), Parsley and Wei (2001), Parsley and Wei (2002) used price dispersion to study market segmentation and integration. In addition, many studies are currently conducted on the impact of market segmentation (Que et al., 2018; Dolnicar, 2019; Shao et al., 2019; Dolnicar, 2020).

Research on GTFEE

Currently, many pieces of literature focus on the relative research of energy consumption and energy efficiency, it involves the categories, development, measurement methods, influencing factors (Mohsin et al., 2019). According to the number of input factors in production, there are a single factor and total factor energy efficiency. The former is usually expressed in terms of energy intensity or energy productivity, with the simple measurement method and available data, it attracts many scholars to use (Moshiri and Duah, 2016; Dong et al., 2018). However, since it cannot include the impact of other factors on output and biased metrics, many scholars have doubted single factor energy efficiency (Wilson et al., 1994; Patterson, 1996). To remedy this deficiency and measure the substitution effect between different input factors, some studies adopt total factor energy efficiency (Hu and Wang, 2006; Honma and Hu, 2009; Borozan, 2018; Ohene-Asare et al., 2020; Chen et al., 2021). Furthermore, researchers have considered the impact of resources and the environment on sustainable economic development, adding environmental factors, energy, and pollution emission into the calculation of total factor energy efficiency (Ramanathan, 2006; Baležentis et al., 2016). This input-output efficiency, which simultaneously considers energy and pollution emissions, is called GTFEE (Hao et al., 2020; Wu et al., 2020). The methods of measuring total factor productivity are generally divided into growth accounting method and econometric method. Specifically, the former includes the Solow residual method and the algebraic index method. One of the econometric methods is the potential output method which is also called Frontier production function, and mainly includes parametric or statistical methods like stochastic Frontier analysis (SFA), nonparametric methods, or mathematical programming like data envelopment analysis (DEA) (Ferrier and Lovell, 1990; Färe et al., 1997). The method of DEA is widely used by scholars (Bian et al., 2013; Mohsin et al., 2021). Furthermore, the current studies on the influencing factors of GTFEE have been carried out from multiple perspectives. including industrial structure (Guo and Yuan, 2020), energy structure (Chien and Hu, 2007), foreign investment (Pan et al., 2020), technological progress (Liu et al., 2016), government intervention (Matraeva et al., 2019), economic development (Wu et al., 2020).

METHODOLOGY AND DATA

Research Method

Basic Linear Model

This article focuses on examining the influence of corruption and market segmentation on China's GTFEE. Considering that GTFEE may be affected by earlier stages, the lagging one-stage variable $lngtfee_{it-1}$ is added to the model. Therefore, we construct the basic econometric model:

$$lngtfee_{it} = \beta_0 + \beta_1 lngtfee_{it-1} + \beta_2 lncor_{it} + \beta_3 lnrd_{it} + \beta_4 lngdp_{it} + \beta_5 lnrdp_{it} + \beta_6 lnurb_{it} + \beta_7 lnopen_{it} + \alpha_i + \nu_t + \varepsilon_{it} \tag{1}$$

$$lngtfee_{it} = \beta_0 + \beta_1 lngtfee_{it-1} + \beta_2 lnsegm_{it} + \beta_3 lnrd_{it} + \beta_4 lngdp_{it} + \beta_5 lnrdp_{it} + \beta_6 lnurb_{it} + \beta_7 lnopen_{it} + \alpha_i + \nu_t + \varepsilon_{it} \tag{2}$$

$$lngtfee_{it} = \beta_0 + \beta_1 lngtfee_{it-1} + \beta_2 lnsegm_{it} + \beta_3 lncor_{it} + \beta_4 (lncor_{it} \times lnsegm_{it}) + \beta_5 lnrd_{it} + \beta_6 lngdp_{it} + \beta_7 lnrdp_{it} + \beta_8 lnurb_{it} + \beta_9 lnopen_{it} + \alpha_i + \nu_t + \varepsilon_{it} \tag{3}$$

where $lngtfee_{it}$ represents GTFEE, and i and t represent province and time. ε_{it} is the random disturbance term. The control variables include economic development (gdp_{it}), R&D investment (rd_{it}), R&D personnel input (rdp_{it}), trade openness ($open_{it}$) and urbanization (urb_{it}).

Threshold Model

Furthermore, we refer to the research of Ren et al. (2021a) and use a dynamic threshold model to separately discuss their impact on GTFEE with corruption and market segmentation as threshold variables. The dynamic threshold panel model combines generalized method of moments (GMM) with a threshold model to study spatial heterogeneity as well as to solve endogeneity problems between variables. Moreover, the dynamic threshold panel model can determine the threshold variable through grid search under different threshold variables and solve potential internal factors in the model. The specific dynamic threshold is modeled as follows.

$$lngtfee_{it} = \beta_0 + \beta_1 lngtfee_{it-1} + \beta_2 lncor_{it} \cdot I\left(lnsegm_{it} \le c\right) + \beta_3 lncor_{it} \cdot I\left(lnsegm_{it} > c\right) + \sum_{k=1}^{5} \beta_k X_{kit} + \alpha_i + \nu_t + \varepsilon_{it} \tag{4}$$

$$lngtfee_{it} = \beta_0 + \beta_1 lngtfee_{it-1} + \beta_2 lnsegm_{it} \cdot I\left(lncor_{it} \le c\right) + \beta_3 lnsegm_{it} \cdot I\left(lncor_{it} > c\right) + \sum_{k=1}^{5} \beta_k X_{kit} + \alpha_i + \nu_t + \varepsilon_{it} \tag{5}$$

where $lnsegm_{it}$ and $lncor_{it}$ are the threshold variable, respectively. c is the threshold value to be estimated. $I(\cdot)$ is an instruction function.

Explanation of Variables

China's Green Total Factor Energy Efficiency

Tone (2001) proposed a non-radial super-efficiency SBM model that includes slack variables, calling it the super-efficiency Slack Based Model (SBM). It is a type of super-efficiency DEA model. Compared with other radial models, the super-efficiency SBM model not only measures all the slack variables, but in the case of considering all inefficiency sources it can accurately measure the efficiency level—that is, the effectiveness of all DMUs (decision-making units) is analyzed first, and then the super-efficiency analysis is performed for the effective DMU. This paper constructs a super-efficiency SBM model that includes all influencing factors of resource consumption, expected output, and undesired output to evaluate green eco-efficiency. Therefore, based on Wu et al. (2020), we establish an SBM model:

$$\gamma^* = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\bar{X}}{X_{i0}}}{1 + \frac{1}{S_1+S_2}\left(\sum_{r=1}^{S_1}\frac{S_r^g}{y_{r0}^g} + \sum_{r=1}^{S_2}\frac{S_r^b}{y_{r0}^b}\right)}$$

$$S.t. \sum_{k=1}^{K}\lambda_k x_{nk} \le x_n;\ \sum_{k=1}^{K}\lambda_k y_{mk} \ge y_m;\ \sum_{k=1}^{K}\lambda_k u_{jk} = u_j;\ \lambda \ge 0$$

where X denotes the input variable (Capital, labor, and energy); Y indicates the expected output (GDP); B denotes the unexpected output (wastewater, waste gas, and waste solid); n, M, and j represent the number of types of input, expected output, and unexpected output. The calculation of GTFEE requires the inclusion of inputs, desired and undesired outputs, in the calculation framework.

Corruption

Government corruption (COR). Corruption not only stimulates rent-seeking activities but also reduces the motivation of firms for energy technology innovation (Del Monte and Papagni, 2001; Svensson, 2005; Ceva and Ferretti, 2021). Given the availability of data, we draw on the study of Hao et al. (2020) and adopt the number of public officials involved in corruption per 10,000 as a proxy variable for regional corruption. The calculation results are shown in **Figures 1**, **2**.

Market Segmentation

One of the difficulties studied in this article is the calculation of the market segmentation indicators of China's provinces. There are currently five types of measurement methods for market segmentation: the production method, trade method, price method, business cycle method, and market survey method. This article refers to the research of Shao et al. (2019) and uses relative price information to calculate the market segmentation in each province. Specifically, it analyzes market segmentation through the difference in commodity prices between regions.

Before measuring the relative price variance, a 3-dimensional (t × m × k) data set needs to be constructed, where t, m, and k represent the year, region and commodity, respectively. We sort out the retail price index of eight categories[1] of commodities of 30 provinces in China.

1) Considering that the original data of this article are a chain index of retail prices of commodities, the relative price is measured by the logarithmic first difference of the price ratio. We define the following:

$$\Delta Q_{ijt}^k = \ln\left(p_{it}^k / p_{jt}^k\right) - \ln\left(p_{it-1}^k / p_{jt-1}^k\right) = \ln\left(p_{it}^k / p_{it-1}^k\right) - \ln\left(p_{jt}^k / p_{jt-1}^k\right)$$

In this way, from the data of 435 pairs of eight types of commodities in the province and city combination in the sample from 2006 to 2017 (12 years in total), the relative prices of 41,760 differential forms can be calculated as ΔQ_{ijt}^k.

2) Changes in commodity prices between regions may be caused by some characteristics of the commodities themselves $|\Delta Q_{ijt}^k|$. This means that not all changes are caused by the differences in the market environment between regions, and differences may also include the nonadditive effects caused by the heterogeneity of

[1]The eight categories of commodities included are grain; clothing; shoes and hats; beverages, tobacco and alcohol; cultural and sports goods; medicines; books, newspapers and magazines; daily necessities and fuel.

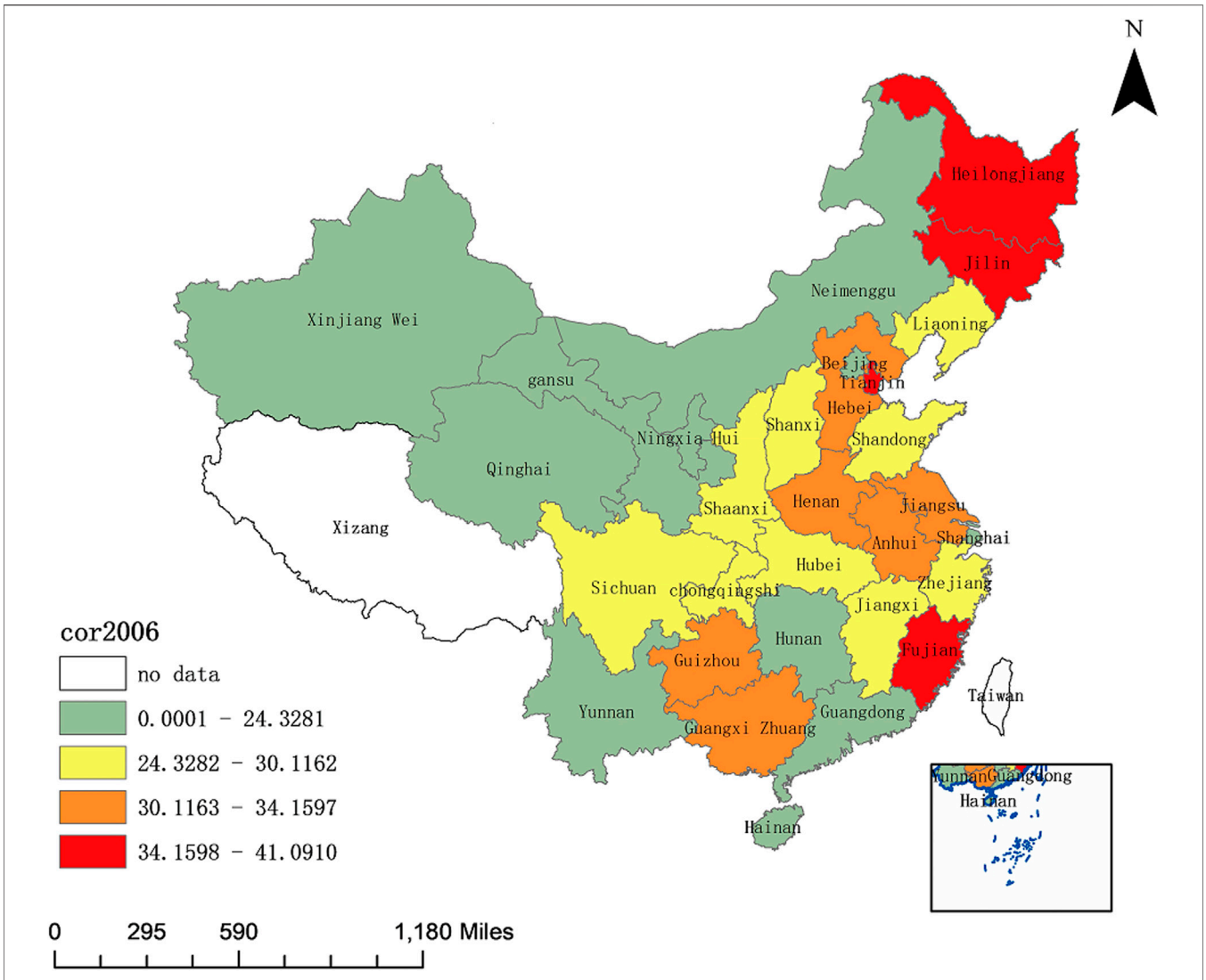

FIGURE 1 | Corruption levels in Chinese provinces in 2006.

commodities, leading to the overestimation of the actual market segmentation index formed by trade barriers.

Therefore, we draw on the de-mean method proposed by Parsley and Wei (2001) and assume $|\Delta Q_{ijt}^k| = a^k + \varepsilon_{ijt}^k$,

Where a^k is the price change caused by the kth commodity itself, and ε_{ijt}^k is related to the special market environment of the two regions i and j. In this article, to eliminate the fixed effect a^k, the relative prices between the provincial and municipal combinations $|\Delta Q_{ijt}^k|$ are averaged to obtain $|\Delta \bar{Q}_t^k|$, and then these 435 $|\Delta Q_{ijt}^k|$ subtract the mean value.

$$q_{ijt}^k = \varepsilon_{ijt}^k - \bar{\varepsilon}_{ijt}^k = \left|\Delta Q_{ijt}^k\right| + \left|\Delta \bar{Q}_t^k\right| = \left(a^k - \bar{a}^k\right) + \left(\varepsilon_{ijt}^k - \bar{\varepsilon}_{ijt}^k\right)$$

In this formula, q_{ijt}^k is the final relative price change, and it is only related to the market segmentation factors between regions and some random factors.

3) Calculate the variance var (q_{ijt}^k) of the relative price fluctuation q_{ijt}^k (k = 1, 2, . . . ,8) of the eight types of commodities in each of the two regions. Then, calculate the relative price variance of the 435 pairs of provinces and obtain the market segmentation index from other provinces and cities across the country, Var (q_{rnt}) $=(\sum_{i \neq j} var\,(q_{ijt})/N$, where n is the region and N is the number of combined provinces and cities. The above calculation process has a total of 360 (=30 × 12) observations.

Control Variables and Data Sources

R&D personnel (rdp_{it}) and R&D capital (rd_{it}) can affect the level of technological innovation, which can contribute to the improvement of GTFEE (Song and Oh, 2015; Yang et al., 2021a). This paper uses R&D capital investment and R&D personnel investment in each province to represent, respectively.

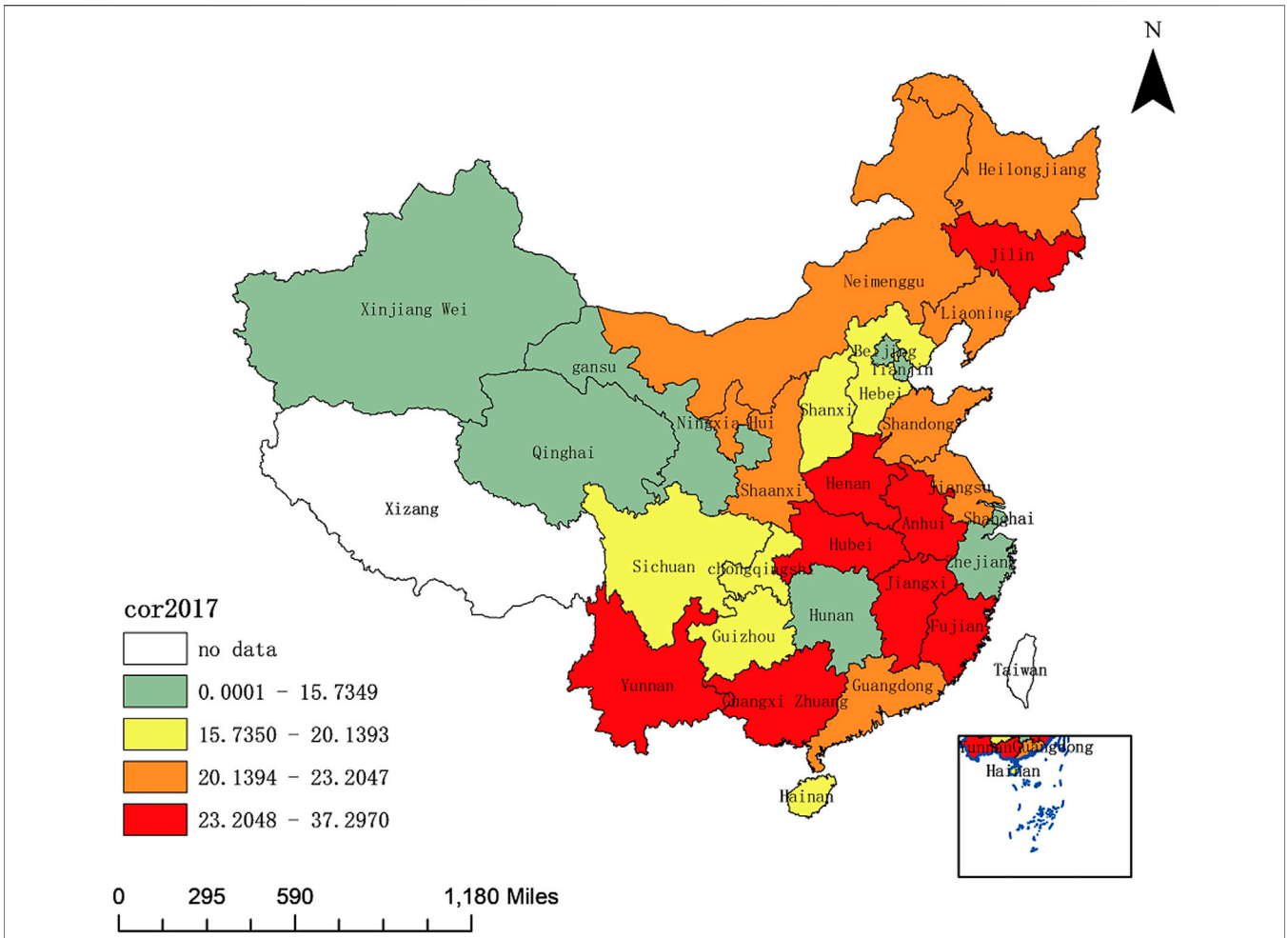

FIGURE 2 | Corruption levels in Chinese provinces in 2017.

The level of economic development (gdp_{it}) can influence the industrial structure and energy utilization efficiency and plays an important role in GTFEE. This paper adopts the GDP of each province to measure it (Yang et al., 2021b).

Trade openness ($open_{it}$) can affect the regional GTFEE by introducing the leading energy-saving technology in developed countries. This paper uses the proportion of the total import and export to GDP to measure it (Li and Hu, 2012; Ren et al., 2021b).

The regional urbanization level (urb_{it}) can adjust the industrial structure, optimize the allocation of resources, and improve the GTFEE (Lv et al., 2020). In addition, it can promote the improvement of residents' living standards and economic growth, but changes in residents' consumption patterns and the construction of urbanization infrastructure will also increase the energy demand. These have important implications for GTFEE. We use the proportion of the urban population to express it.

This paper uses panel data of 30 provinces from the *Wind database, China Energy Statistical Yearbook, China Statistical Yearbook*, *China Inspection Yearbook, provincial inspection reports* and the statistical yearbooks of various provinces in China. The specific descriptive statistics are shown in **Table 1**.

RESULTS AND DISCUSSION

Corruption and GTFEE

First, we examine the impact of corruption on GTFEE. This study uses OLS, FE, RE, and feasible generalized least square (FGLS) to analyze the relationship between corruption and GTFEE. The regression results show that the coefficient of corruption is significantly negative, indicating that corruption inhibits the increase of GTFEE. Another cause of the endogeneity problem is that conventional models such as fixed effects (FE) and random effects can have estimation bias. To account for this, the lagged term of GTFEE is introduced in our empirical model. Moreover, the GMM approach, which can obtain consistent estimation results, was applied. To test whether the instrumental variable is overidentified, this paper reports the Hanse test. **Table 2** shows the corresponding estimation results based on the GMM

TABLE 1 | The variables description.

Variable	Definition	Obs	Mean	Std. Dev	Min	Max
GTFEE	Green total factor energy efficiency	360	0.5516	0.1800	0.2324	1.1084
SEGM	Market segmentation	360	0.3479	0.2782	0.0114	1.4764
COR	Regional corruption	360	24.7129	6.8828	7.8750	46.3227
RDP	R&D personnel	360	6.2481	8.9534	0.0085	45.7342
RD	R&D capital	360	2.1496	3.2228	0.0040	18.6503
GDP	Economic Development	360	1.4276	1.2059	0.0638	6.6918
OPEN	Trade openness	360	0.3122	0.3750	0.0086	1.7215
URB	Urbanization level	360	0.5353	0.1371	0.2745	0.8961

TABLE 2 | The results of corruption on GTFEE.

Variable	OLS	FE	RE	FGLS	GMM
L.lngtfee	—	—	—	—	0.568***
	—	—	—	—	(43.070)
Lncor	−0.077***	−0.055**	−0.066**	−0.062***	−0.047***
	(−2.883)	(−2.119)	(−2.427)	(−4.829)	(−6.292)
Lnrd	−0.270***	−0.091***	−0.136***	−0.254***	−0.002
	(−8.450)	(−3.076)	(−4.677)	(−24.889)	(−0.201)
Lngdp	0.292***	0.298***	0.241***	0.302***	−0.015
	(10.139)	(6.286)	(6.049)	(22.294)	(-0.683)
Lnrdp	0.169***	0.060***	0.100***	0.148***	0.011***
	(5.718)	(2.660)	(4.264)	(13.117)	(3.457)
Lnopen	0.119***	0.015	0.039***	0.115***	0.023***
	(10.341)	(1.426)	(3.647)	(24.411)	(7.106)
Lnurb	0.510***	−0.547***	−0.134	0.527***	0.065**
	(9.018)	(−5.844)	(−1.638)	(18.922)	(2.246)
_cons	−0.077	−0.882***	−0.582***	−0.099**	—
	(−0.945)	(−8.370)	(−5.718)	(−2.329)	—
AR(1)	—	—	—	—	−1.54
	—	—	—	—	[0.124]
AR(2)		—	—	—	0.89
	—	—	—	—	[0.371]
Hansen test	—	—	—	—	28.67
	—	—	—	—	[0.683]
R^2/Wald test	0.7900	0.2264	0.4796	15,738.81***	4,412.36***
N	360	360	360	360	360

****, **, and * are significance at the 1, 5, and 10% levels; t or z statistics in ().*

estimators. We find that the lag term of GTFEE is positive, which means the GTFEE has obvious dependency features. An important reason is that the corruption of officials seeking profit by power exacerbates the misallocation of resources such as labor and capital, as well as market information asymmetry, which reduces GTFEE. This conclusion is consistent with Hao et al. (2020).

Market Segmentation and GTFEE

Given the endogeneity problems, this paper uses system GMM to examine the impact of market segmentation on GTFEE (**Table 3**). It can be found that the negative relation between market segmentation and GTFEE is clear. Obviously, after increasing the control variable continuously, we find the estimated coefficient is still negative, that is the above conclusion is valid. According to the regression coefficient, every 1% increase in market segmentation can reduce the GTFEE of China by 0.003%, which shows that the region can improve GTFEE through the process of market integration and industrial agglomeration. The reason for this result may be that market segmentation reduces the flow of factors such as labor and technology. Local governments ignore comparative advantages and carry out local protection, which leads to misallocation of resources, hinders technological innovation and GTFEE (Ren et al., 2021a). Therefore, the government can increase GTFEE by breaking the market segmentation, allowing the free flow of production factors, and enhancing regional market integration.

The Moderating Effect of Market Segmentation and Corruption on GTFEE

The conclusion of the above tests show that corruption and market segmentation have a significant negative impact on GTFEE. In this part, we analyze the moderating effect of market segmentation through the SYS-GMM method and the stepwise regression method. **Table 4** indicates the empirical result of the moderating effect. We found that the interaction term coefficients are all significantly negative. It shows that as market segmentation increases, the negative effect of corruption on the GTFEE is also increasing. Moreover, local government corruption exacerbates market fragmentation and reduces innovation resource flows, resource allocation efficiency, and GTFEE (Zhao et al., 2021).

The Results of the Threshold Model

This paper chooses corruption and market segmentation as threshold variables, respectively. The *p*-values of Wald statistic and AR 2) are greater than 0.1 (**Table 5**), showing that the variables have no serial correlation and the instrumental variable is valid. The specific threshold results are shown in **Table 6**.

Corruption is being considered as the threshold variable to investigate the effect of market segmentation on GTFEE under different levels of corruption. We find that as corruption exacerbates, the regression coefficient of market segmentation increases, indicating that the more serious the corruption is, the greater the negative effect of market segmentation on GTFEE. The reason for this may be because with the increase of corruption, to prevent the entry of other competitors, local government officials often choose to set up administrative barriers to protect local enterprises to obtain

TABLE 3 | The empirical results of market segmentation on GTFEE.

Variable	SYS-GMM	SYS-GMM	SYS-GMM	SYS-GMM	SYS-GMM	SYS-GMM
L.lngtfee	1.025***	1.011***	1.030***	1.031***	0.968***	0.964***
	(1,066.198)	(474.876)	(303.568)	(303.205)	(179.048)	(178.149)
lnsegm	−0.007***	−0.003***	−0.005***	−0.005***	−0.003***	−0.003***
	(−121.775)	(−4.642)	(−6.382)	(−5.925)	(−4.384)	(−3.937)
Lnrd	—	0.003***	0.010***	0.013***	0.009***	0.004
	—	(7.659)	(14.188)	(20.603)	(3.579)	(0.928)
lngdp	—	—	−0.016***	−0.015***	−0.004	−0.001
	—	—	(−8.589)	(−8.426)	(−1.102)	(−0.334)
lnrdp	—	—	—	−0.005***	−0.005*	-0.001
	—	—	—	(−5.598)	(−1.723)	(−0.282)
Lnopen	—	—	—	—	0.022***	0.020***
	—	—	—	—	(16.165)	(11.298)
Lnurb	—	—	—	—	—	0.018*
	—	—	—	—	—	(1.828)
_cons	−0.015***	−0.034***	−0.020***	−0.010*	0.001	0.004
	(−3.404)	(−57.662)	(−3.788)	(−1.784)	(0.081)	(0.396)
AR(1)	−1.71	−1.67	−1.70	−1.69	−1.69	−1.69
	[0.087]	[0.095]	[0.089]	[0.091]	[0.090]	[0.091]
AR(2)	0.74	0.78	0.76	0.77	0.74	0.74
	[0.458]	[0.438]	[0.446]	[0.441]	[0.461]	[0.458]
Hansen test	29.69	28.78	28.44	28.15	28.21	27.50
	[0.328]	[0.321]	[0.288]	[0.254]	[0.208]	[0.193]
N	360	360	360	360	360	360

TABLE 4 | The estimated results of moderating effect.

Variable	SYS-GMM Model					
L.lngtfee	1.019***	1.011***	1.007***	1.018***	0.974***	0.963***
	(730.061)	(178.951)	(88.893)	(151.642)	(125.911)	(85.650)
Lnsegm	0.357***	0.304***	0.323***	0.358***	0.317***	0.312***
	(12.791)	(21.689)	(10.786)	(12.780)	(13.854)	(14.042)
Lncor	−0.962***	−0.828***	−0.865***	−0.956***	−0.823***	−0.800***
	(−13.087)	(−22.466)	(−11.005)	(−13.257)	(−13.882)	(−13.283)
*lncor*lnsegm*	−0.115***	−0.098***	−0.103***	−0.114***	−0.100***	−0.098***
	(−13.043)	(−23.114)	(−10.532)	(−12.887)	(−13.444)	(−13.368)
Lnrd	—	0.002**	0.004*	−0.004	0.006	−0.002
	—	(2.082)	(1.832)	(−0.872)	(1.584)	(−0.199)
Lngdp	—	—	−0.003	−0.001	0.004	0.011
	—	—	(−0.394)	(−0.126)	(0.488)	(0.893)
Lnrdp	—	—	—	0.006	−0.007	−0.003
	—	—	—	(1.255)	(−1.355)	(−0.433)
lnopen	—	—	—	—	0.019***	0.019***
	—	—	—	—	(7.149)	(6.170)
Lnurb	—	—	—	—	—	0.028
	—	—	—	—	—	(0.746)
_cons	3.009***	2.579***	2.730***	3.013***	2.629***	2.574***
	(12.958)	(21.444)	(11.194)	(13.152)	(14.475)	(14.668)
AR(1)	−1.83	−1.79	−1.76	−1.78	−1.82	−1.81
	[0.067]	[0.073]	[0.079]	[0.075]	[0.069]	[0.070]
AR(2)	0.33	0.41	0.44	0.37	0.41	0.42
	[0.743]	[0.681]	[0.662]	[0.710]	[0.685]	[0.678]
Hansen test	27.71	28.22	24.89	26.64	25.84	25.62
	[0.321]	[0.850]	[0.356]	[0.775]	[0.213]	[0.179]
N	360	360	360	360	360	360

local GDP growth, which further hinders the free flow of resources such as technology and talent, and reduces energy efficiency.

Furthermore, this paper examines the role of corruption on GTFEE under different market segmentation levels. The study found that with the exacerbation of market segmentation, the

TABLE 5 | The threshold tests.

Variable	Threshold value	Wald	*p*-Value	95% Confidence interval	
Corruption	–9.2276	498.4594	0.0000	–9.5527	–7.3389
	–9.2276	498.4594	0.0000	–9.5527	–7.3389
Market segmentation	3.3965	80.99856	0.0000	2.6452	3.6106
	3.3965	80.99856	0.0000	2.6452	3.6106

TABLE 6 | The results of threshold model.

Variable	Cor		Segm	
	SYS-GMM	DIF-GMM	SYS-GMM	DIF-GMM
$lngtfee_{it-1}$	0.981***	0.561***	1.018***	0.506***
	(111.27)	(27.39)	(107.25)	(24.57)
lnrd	–0.010***	–0.002	0.016***	–0.038***
	(3.40)	(–0.13)	(5.14)	(–4.00)
lngdp	–0.011*	–0.001	–0.045***	0.056***
	(–1.75)	(–0.03)	(–5.60)	(3.67)
lnrdp	0.001	0.007	0.012***	0.025***
	(0.22)	(1.54)	(3.78)	(4.17)
Lnopen	0.011***	0.008***	0.005**	-0.029***
	(5.33)	(9.69)	(2.05)	(–7.39)
$q_{it} \leq C$	–0.033***	–0.069***	–0.0037***	–0.006***
	(–3.44)	(–4.45)	(–.13)	(–3.89)
$q_{it} > C$	–0.040***	–0.074***	–0.0044***	–0.007***
	(–3.95)	(–4.67)	(–4.05)	(–4.79)
_cons	0.134***	—	–0.017***	—
	(4.89)	—	(–3.08)	—
AR (1)	–1.84	–1.73	–1.71	–1.68
	[0.066]	[0.083]	[0.088]	[0.094]
AR (2)	0.58	0.72	0.78	0.82
	[0.563]	[0.472]	[0.437]	[0.412]
Hansen test	27.87	28.11	27.70	27.75
	[0.926]	[0.512]	[0.684]	[0.889]
Wald test	392,589.80***	6,106.34***	692,995.96***	1,499.68***
	[0.000]	[0.000]	[0.000]	[0.000]
N	360	360	360	360

regression coefficient of corruption also increases, indicating that severe market segmentation leads to the stronger negative effect of corruption on GTFEE. The reason for this phenomenon is that in areas with severe market segmentation, local officials excessively use administrative power to interpose the allocation of resources. In this case, the market divides the competition of enterprises, restricts the expansion of the production possibility Frontier of enterprises, and distorts the technical efficiency of firms, thereby reducing the GTFEE.

Robustness Test

To verify the reliability of the above results (**Tables 1–5**), the robustness test is conducted on the relevance between corruption, market segmentation, and GTFEE. The internal relevance between the three variables is investigated by taking the GTFEE that is measured through DDF-GML model as the explained variable. Furthermore, we re-estimate the model using the OLS and the spatial econometric approach. The results in **Table 7** show that the main variables (*lncor*, *lnsegm, and lncor×lnsegm*) are negative, which is consistent with the results above and confirms the robustness of the conclusion.

TABLE 7 | The results of the robustness test.

Variable	OLS	SAR	OLS	SAR	SAR
lncor	–0.050*	–0.063**	—	—	–0.231
	(–1.86)	(v2.36)	—	—	(–1.49)
Lnsegm	—	—	–0.032*	–0.033*	0.083
	—	—	(–1.67)	(–1.78)	(1.47)
lncor×lnsegm	—	—	—	—	–0.030*
	—	—	—	—	(–1.66)
Lnrd	0.047	0.001	0.010	-0.001	0.034
	(1.46)	(0.03)	(0.24)	(-0.02)	(1.08)
Lngdp	–0.039	–0.040	–0.050*	–0.043	–0.099
	(–1.36)	(–1.45)	(–1.73)	(–1.52)	(–1.58)
Lnrdp	0.034	0.070**	0.069*	0.068**	–0.074***
	(1.14)	(2.04)	(1.91)	(1.96)	(–2.90)
Lnopen	0.106***	0.113***	0.126***	0.121***	–0.009
	(9.18)	(8.76)	(9.54)	(9.42)	(–0.84)
Lnurb	0.318***	0.252***	0.302***	0.279***	–0.032
	(5.60)	(4.50)	(5.21)	(4.96)	(–0.30)
_cons	–0.012	—	–0.463***	—	—
	(–0.15)	—	(–2.96)	—	—
Spatial_rho	—	0.198***	—	0.165***	-0.369***
	—	(3.83)	—	(3.26)	(-4.36)
Sigma2_e	—	0.020***	—	0.020***	0.003***
	—	(13.42)	—	(13.44)	(13.27)
R^2	0.703	0.784	0.714	0.792	0.223
N	360	360	360	360	360

CONCLUSION AND POLICY IMPLICATION

This study first establishes an SBM model to measure GTFEE by using considering undesirable outputs, environmental supervision indicator system as unexpected output, and then use the price-relative price method to calculate the market segment index. Second, taking China as the research object, this paper conducts the basic linear regression model to discuss the relationship between corruption, market segmentation, and GTFEE. Finally, the threshold model is adopted to analyze the effect of corruption and segmentation on GTFEE. The main empirically test conclusion is as follows.

First, we found that corruption has a significantly negative effect on GTFEE. With the increase of corruption, the GTFEE will be reduced. Second, when adding different control variables gradually, the stepwise regression method is adopted to test the effect between market segmentation and GTFEE. This

study found that market segmentation reduces the GTFEE. In the robustness test, the conclusion about the influence of corruption on GTFEE, market segmentation on GTFEE are both valid. Finally, corruption and market fragmentation significantly reduce GTFEE when they are regarded as threshold variables. Based on the above research, this paper puts forward some recommendations.

1) GTFEE has obvious spatial dependence and is greatly affected by the GTFEE of adjacent areas. If the GTFEE of adjacent areas is higher, the local GTFEE will increase faster. To promote market integration and achieve regional integration, the government should increase the intensity of supervision and governance of official corruption, which can make government governance more transparent, prevent local governments from taking bribes, and reduce officials' incentives to formulate local protection policies. Furthermore, corruption and market segmentation are alleviated, factor resources can flow freely, and market integration is promoted, which is conducive to the improvement of GTFEE.
2) In the process of economic transformation, the government should focus on market-oriented reforms, reduce excessive intervention, release more power to the market, and ensure the free flow of resources. The main reason is that if the government intervenes too much, the local government will use the resources and power at its disposal to set up and seek rents, breed corruption, and exacerbate market segmentation. The government should improve the degree of market integration, and increase the flow of resources, talents, and technology between regions. Moreover, break regional protectionism, learn from regions with high GTFEE, introduce talents, learn advanced technology, promote the free flow of factor resources and improve GTFEE.
3) Local governments should find and solve the key factors restricting the improvement of local GTFEE according to their regional energy advantages. Implement differentiated energy efficiency improvement policies for different development stages. In addition, optimize the energy consumption structure, reduce the demand for fossil energy such as coal, and strengthen the development and utilization of green and clean energy and renewable energy. As the developed eastern regions have the advantages of geographical location, traffic conditions, and economic opening, it is necessary to maintain the regional advantages, reduce the degree of market segmentation, promote the free flow of energy factors between regions, and establish a unified, and orderly energy market. Moreover, these regions need to vigorously develop low-energy-consuming industries. For the central and western regions with relatively backward economic and technological development, it is necessary to strengthen inter-regional cooperation and promote the free flow of production factors and technology. They also need to appropriately raise local energy prices and improve the pricing mechanism in the energy market.

Although this paper examines the relationship between corruption, market segmentation, and GTFEE, there are still some limitations. For example, this article uses provincial data due to data availability. It would be interesting to study this question at the industry or city level in the future if more detailed data are available. In terms of research methods, the spatial econometric models and techniques can be used to analyze the spatial spillover effects of corruption and market segmentation on the GTFEE in future research. In addition, future research can focus on the impact of corruption, market segmentation on carbon emissions, economic growth or excess capacity.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://www.stats.gov.cn/tjsj/ndsj/.

AUTHOR CONTRIBUTIONS

MD: Data curation, Formal analysis, Writing-original draft. SR: Software, Visualization, Empirical analysis. QZ: Funding acquisition, Supervision, Writing–original draft.

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Antecedents of Consumer's Purchase Intention Towards Energy-Efficient Home Appliances: An Agenda of Energy Efficiency in the Post COVID-19 Era

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This study focuses on the energy efficiency in the past COVID-19 era and targeted the young population of Pakistan who are facing the critical situation of COVID-19 era and much aware that this situation will badly affect the energy situation when COVID-19 will end and they also aware that energy efficient appliances will be the most valuable products after the COVID-19 era. Data was collected from five major cities of Pakistan and analyzed by applying structure equation modelling through smart-PLS 3.3. Results show that knowledge of eco-labels has significant impact on perceived functional values, green trust and purchase intention of energy efficient home appliances. Results further indicate that consumers social responsibility has significant impact on personal norms and purchase intention of energy efficient home appliances. Moreover, functional value and green trust mediates the relationship of knowledge of eco-labels and purchase intention of energy efficient home appliances. Furthermore, attitude towards energy efficient appliances mediates the relationship between consumers social responsibility and purchase intention but surprisingly no mediating affect of attitude between consumer social responsibility and purchase intention of energy efficient home appliances. This study presents an antecedent model for predicting energy-efficient home appliances based on consumer awareness. This study will help companies for technology innovation and improvements in the efficiency of household appliances are among the key functional values that companies should emphasize, in order to attract consumers to value the surprising energy-saving effects of appliances.

Keywords: eco-labels, consumer social responsibility, functional value, green trust, energy efficiency, purchase intention

INTRODUCTION

Household electrical appliances have sparked a massive increase in energy consumption, resulting in increased levels of pollution. A non-energy-efficient appliance can also waste electricity, which is counterproductive to reducing emissions and saving energy. A move toward energy-efficient appliances could help alleviate the current situation, where severe ecological and environmental problems exist (Tan et al., 2017; Ahmad et al., 2021a).

Since the mid-1980s, ecological behavior has shifted dramatically toward a higher standard of living for people. In addition to contributing to an excellent quality of life, a good environment also boosts economic growth (Joshi et al., 2019; Ahmad et al., 2022). People are developing and evolving, and as a result there is a growing need for better services like computers, mobile phones, the internet, televisions, and fast trains (Elavarasan et al., 2021a). Ecological development and reduction of greenhouse gas emissions can be boosted by utilizing resources efficiently (Wang et al., 2019). Eco-efficiency is the process of using resources efficiently to achieve these goals. From 2011 to 2030, energy consumption is expected to increase by 36% (Nguyen et al., 2017). Approximately 80% of greenhouse gas emissions are attributed to fossil fuels (Guomin Li et al., 2019). Middle-income economies consume the most fossil fuels due to their reliance on energy for economic development. By 2050, energy efficiency is expected to reduce greenhouse gas emissions by 50%, according to the American Council for Energy-Efficient Economy (ACEEE). Reduced greenhouse gas emissions and increased economic growth are linked to middle-income countries' energy efficiency (Wang J et al., 2017).

The energy sector has experienced tremendous growth all over the world. Developed countries such as Switzerland, United Kingdom, Australia, and the US have given much attention to consumer energy consumption (Sreen et al., 2018; Elavarasan et al., 2021b). The use of energy in households is expected to rise by 30% in developing nations by 2040, but little is known about this area. According to Ali et al. (2021), 89% of Asians have access to electricity since 2000, which is 75% of the world's population. According to population statistics, Pakistan is the fifth largest nation in the world. It has the highest population growth rate (2.0%). Pakistan consumes 85% of its energy domestically. Increasing usage of home appliances by the middle class will further increase the consumption of domestic energy (Bhutto et al., 2021; Elavarasan et al., 2022a).

The marketing of energy-efficient appliances has led to increasing familiarity among Pakistani consumers. Pakistan's appliance market has not gained a lot of market share from energy-efficiency appliances (Ali et al., 2021). In light of current sales figures, it is apparent that energy-efficient appliances are sometimes several times as expensive as common appliances. The poor price/performance ratio discourages many consumers from buying it, which lowers their enthusiasm (Hua & Wang, 2019; Gul et al., 2021a). The savings on electricity bills are not considered sufficient for many consumers to justify the higher price of these new and advanced energy-efficient appliances (Jamil et al., 2021a). Moreover, energy-efficient appliances are made from better materials, have better internal components, and have better external hardware than typical appliances, but consumers are not aware of these advantages. Energy-efficient appliances therefore don't attract new customers (Abu-Elsamen et al., 2019; Elavarasan et al., 2022b).

The study explores how consumers are likely to purchase energy-efficient products in the context of an analytical framework. A model is developed that accounts for important factors influencing consumers' decisions. Akroush et al. (2019) asserted that positive attitudes are indicators of intentions. The importance of product labels was emphasized by Jhanji (2021). They also said that developing a favorable attitude to the product involves information on the labeling. Eco-labels promote the trustworthiness of green products and do so by reducing information asymmetry. To make environmentally friendly products acceptable, it is imperative to understand how eco-labels work (Gul et al., 2021b). Consumers who are environmentally conscious care for the environment and want to help improve the quality of the environment. Consumers' perception of social responsibility, norms perceived, and trust perceived are key factors that affect their ecological behavior (Liu et al., 2020; Fang et al., 2022). In the context of environmentally friendly products, perceived green trust in the manufacturer is another potential predictor. Perceived green trust can increase product acceptance among consumers (Hao et al., 2021; Iqbal et al., 2021). Moreover, the perception of functional values of products is an essential factor when it comes to purchasing home appliances. Home appliances that are energy-efficient are extensively discussed in literature as a way to reduce energy consumption (Jamil et al., 2022). It seems, however, that very little research has been conducted regarding consumers' knowledge of eco-labels and the benefits of energy-efficient products. Following COVID-19, the study's findings will be valuable to policymakers and strategists seeking to increase adoption of energy-efficient home appliances.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Knowledge of Eco-Labels, Functional Value, Green Trust and Purchase Intention

In the green product market, eco-labels are important marketing tools to reduce information asymmetry. With the promotion of green products, eco-labeling is becoming more prevalent at both business and communication levels (Ahmad B, et al., 2021; Apipuchayakul & Vassanadumrongdee, 2020). Consumers' perception and evaluation of eco-labels are particularly related to their knowledge of eco-labels (Naseem et al., 2020). When consumers evaluate eco-labels in a holistic way, this reduces information asymmetry about green products, which leads to more informed decisions. Al-Gasawneh & Al-Adamat (2020) concluded on consumer preferences for certified wood showed that knowledge about eco-labels plays a big role in consumer preferences. The study of Issock et al. (2018) showed how the consumers' ecological behavior is shaped by their knowledge and trust of eco-labels. The importance of eco-labels has been

emphasized by Yue et al. (2021), who suggest that learning about eco-labels will lead people to buy greener products. Consumers are more likely to believe eco-labels are credible and this helps them make better decisions when purchasing products. As Lopes & Veiga (2019) examined the factors affecting organic food, brands and reputations, labels, and the certification bodies' reputations were deemed integral to establishing the consumers' trust. Researchers have brought forth the importance of eco-label knowledge in establishing a trust for eco-label products (Irfan et al., 2021a). The arguments above suggest that product values and green trust will be affected by eco-label knowledge. Hence, we proposed following hypotheses:

H1: Consumer's perceived knowledge of eco-labels has significant impact on purchase intention of energy efficient appliances.

H2: Consumer's perceived knowledge of eco-labels has significant impact on perceived functional value of energy efficient appliances.

H3: Consumer's perceived knowledge of eco-labels has significant impact on perceived green trust.

H4: Perceived functional value has significant impact on purchase intention of energy efficient home appliances.

H5: Perceived green trust has significant impact on purchase intention of energy efficient home appliances.

Consumer's Social Responsibility, Personal Norms, Attitude and Purchase Intention

Social responsibility is the most influential factor to the consumption of energy efficient appliances among ethical consumers (Irfan, Elavarasan, et al., 2021b; Jabeen et al., 2019; Song et al., 2019). Generally, consumer social responsibility relates to the willingness of consumers to acknowledge the interests of others, perform their duties as they are expected to, and honor their promises. According to Liao et al. (2020), consumer social responsibility refers to making conscious and deliberate decisions about certain products based on personal moral beliefs. Zhang et al. (2020) discussed that individual belief that it is their responsibility to support energy efficient appliances was conceptualized as the concept of responsibility (Razzaq et al., 2020; Irfan et al., 2021c). As a matter of fact, personal norms define a person's standards of behavior and ethical beliefs, as well as his or her beliefs about what is right or wrong toward certain objects. Responsibility is the driving force behind moral obligation (Joshi et al., 2019; Ahmad et al., 2020a; Islam et al., 2022). Norms and values affect how people feel responsible for exhibiting prosocial behaviors. Individuals' attributions of responsibility for their behavior can affect their norms regarding behavior, according to studies (Khan et al., 2021; Nuvvula et al., 2022). An individual's personal norms become more firmly established if he or she is responsible for a certain behavior. In the same manner, individuals who feel responsible for supporting energy efficient products purchase these products with higher personal standards (Ali et al., 2019).

The attitude of an individual is defined as a preference towards certain objects, ideas, or behaviors. Researchers have hypothesized that attitude is the judgement and evaluation of a particular object based on its abstract associations, and a psychological tendency that has its expression in the degree of favor or disfavor one accords to it (Aguiar-Quintana et al., 2021; Naseem et al., 2021; Razzaq et al., 2021). An individual's likelihood of purchasing a particular product is defined as his or her purchasing intention. A person's purchasing intention can be used to measure their likelihood to purchase a certain product. If a consumer has a positive attitude towards a product, the greater the likelihood that he/she will purchase the product (Ahmad, et al., 2021b; Chavez et al., 2020; Razzaq et al., 2020). An individual's attitude toward a certain product is measured by their positive or negative evaluations thereof (Jamil et al., 2021b; Tanveer et al., 2021). An attitude is defined as a set of beliefs, feelings, and thoughts towards a product, which leads to a specific action to be taken. The attitudes of consumers toward buying energy-efficient products significantly changed their intentions to buy such products (Nguyen et al., 2018). Hence, we proposed following hypotheses:

H6: Consumer's perceived social responsibility has significant impact on purchase intention of energy efficient home appliances.

H7: Consumer's perceived social responsibility has significant impact on perceived personal norms towards energy efficient home appliances.

H8: Consumer's perceived social responsibility has significant impact on consumer's perceived attitude towards buying energy efficient home appliances.

H9: Perceived personal norms towards energy efficient appliances has significant impact on purchase intention of energy efficient home appliances.

H10: Perceived attitude towards energy efficient appliances has significant impact on purchase intention of energy efficient home appliances.

Mediating Role of Perceived Functional Value

Consumers need to keep an eye on the functions of eco-friendly products when purchasing them (Abu-Elsamen et al., 2019; Irfan et al., 2020; Wu et al., 2021). Functional values are based on the quality, durability, and cost of the product. It is clear from the preference of environmentally friendly consumers for products such as aerosols, natural ingredients in cosmetics, organic vegetables, and biodegradable products that fair prices play a significant role in their decisions (Gahlot Sarkar et al., 2019; Sarfraz et al., 2021; Xiang et al., 2022). Consumers' decisions on energy-efficient refrigerators are largely influenced by their price and durability. The functional value of products is strongly associated with purchase intentions and product usage, suggests research. Buying energy-efficient appliances requires a focus on functional values (Akroush et al., 2019; Ahmad et al., 2020b). Hence, we proposed following hypothesis:

H11: Perceived functional value mediates the relationship of perceived knowledge of eco-labels and purchase intention of energy efficient home appliances.

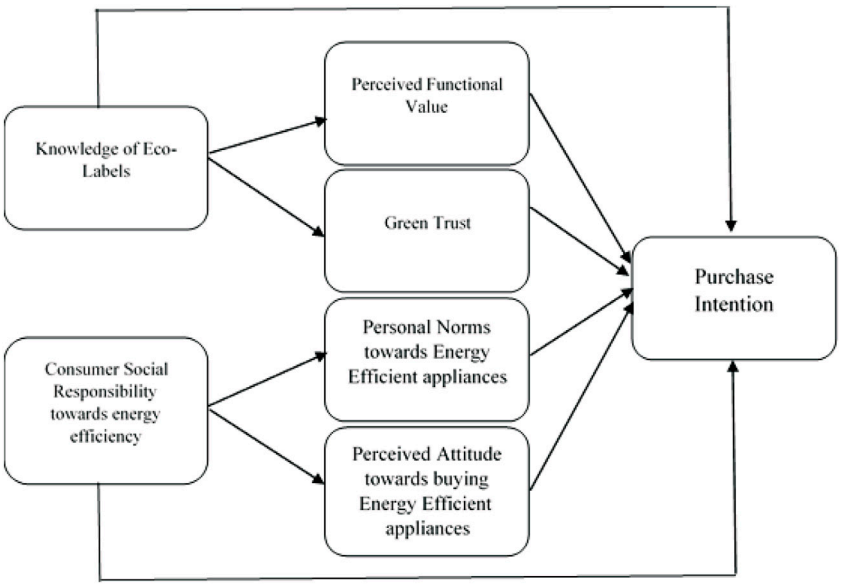

FIGURE 1 | Conceptual framework.

Mediating Role of Green Trust

Consumer behavior is fundamentally influenced by trust. The idea is that one party expects another to perform the task. Several studies have found that trust predicts purchase intentions of consumers, including Chen et al. (2015). Guangxia Li G et al. (2021) argues that green trust is one of the critical factors affecting consumers' purchasing behavior in the context of environmental marketing. Green trust of customers is posited to improve green product purchase intentions by (Khetarpal & Singh, 2020; Yang et al., 2021). It has been observed that consumers' pro-environmental behavior is positively affected by trust in eco-labels (Li N et al., 2021; Mohsin et al., 2021). Despite this, many studies have revealed that consumers' trust is sometimes unrelated to their purchase intentions. A study by Helleno et al. (2017) found that Brazilians' trust in organic foods did not influence their purchasing decisions. Several studies have relied on trust in the decision to buy an environmentally friendly product, but the results have been inconsistent. Green trust can, therefore, influence consumers' intentions to purchase energy-efficient appliances (Awan et al., 2021a; Sreen et al., 2021). Hence, we proposed following hypothesis:

H12: Perceived green trust mediates the relationship of perceived knowledge of eco-labels and purchase intention of energy efficient home appliances.

Mediating Role of Personal Norms

Personal norms are the standards of expectation faced by each individual towards a given object and are based on a set of values that are internalized and applied accordingly (Nguyen et al., 2021). Several researchers have proposed that an individual's beliefs about a behavior shape the way in which he or she responds to that behavior. In other words, attitude toward a particular behavior stems from an individual's assessment of the behavior's value (Awan FH. et al., 2021; Siyal et al., 2021). Individuals may be triggered to adopt personal norms by feeling that they must take action in order to protect themselves from negative outcomes (Jamil et al., 2021c). When people have favorable personal norms, i.e., they believe a specific behavior results in a positive outcome, they adopt a positive attitude toward it (Nguyen et al., 2019). Hence, we proposed following hypothesis:

H13: Consumer's Perceived personal norms mediate the relationship of consumer's perceived social responsibility and purchase intention of energy efficient home appliances.

Mediating Role of Perceived Attitude

A person's attitude is a "state of mental readiness acquired by experience" affecting responses towards people, objects, and situations. Several studies indicate that consumers' positive attitude plays a significant role in determining their environmental behavior (Zhang & Tao, 2020; Shimul et al., 2021). Various researchers have concluded that attitude is a significant determinant of energy-efficient appliance purchases. Purchasing intentions among consumers are influenced by their attitudes towards energy-efficient home appliances (Awan et al., 2021c; Joshi et al., 2022). Hence, we proposed following hypothesis:

H14: Consumer's perceived attitude mediate the relationship of consumer's perceived social responsibility and purchase intention of energy efficient home appliances (see **Figure 1**for all relationships).

METHODOLOGY

A well-structured questionnaire has been distributed to the consumers who are coming to home appliances sections in

TABLE 1 | Reliability and validity analysis.

Constructs	*Items*	*Loadings*	*Cα*	*CR*	*AVE*
Perceived Attitude	PA1	0.815	0.785	0.874	0.699
	PA2	0.842			
	PA3	0.850			
Consumer Social Responsibility	PCSR1	0.852	0.778	0.871	0.692
	PCSR2	0.855			
	PCSR3	0.788			
Perceived Functional Values	PFV1	0.901	0.709	0.872	0.774
	PFV2	0.858			
Green Trust	PGT1	0.792	0.859	0.904	0.703
	PGT2	0.842			
	PGT3	0.851			
	PGT4	0.867			
Purchase Intention	PI1	0.881	0.841	0.904	0.758
	PI2	0.853			
	PI3	0.877			
Perceived Knowledge of Eco-Labels	PK1	0.836	0.835	0.901	0.753
	PK2	0.898			
	PK3	0.867			
Personal Norms	PPN1	0.911	0.841	0.903	0.757
	PPN2	0.848			
	PPN3	0.850			

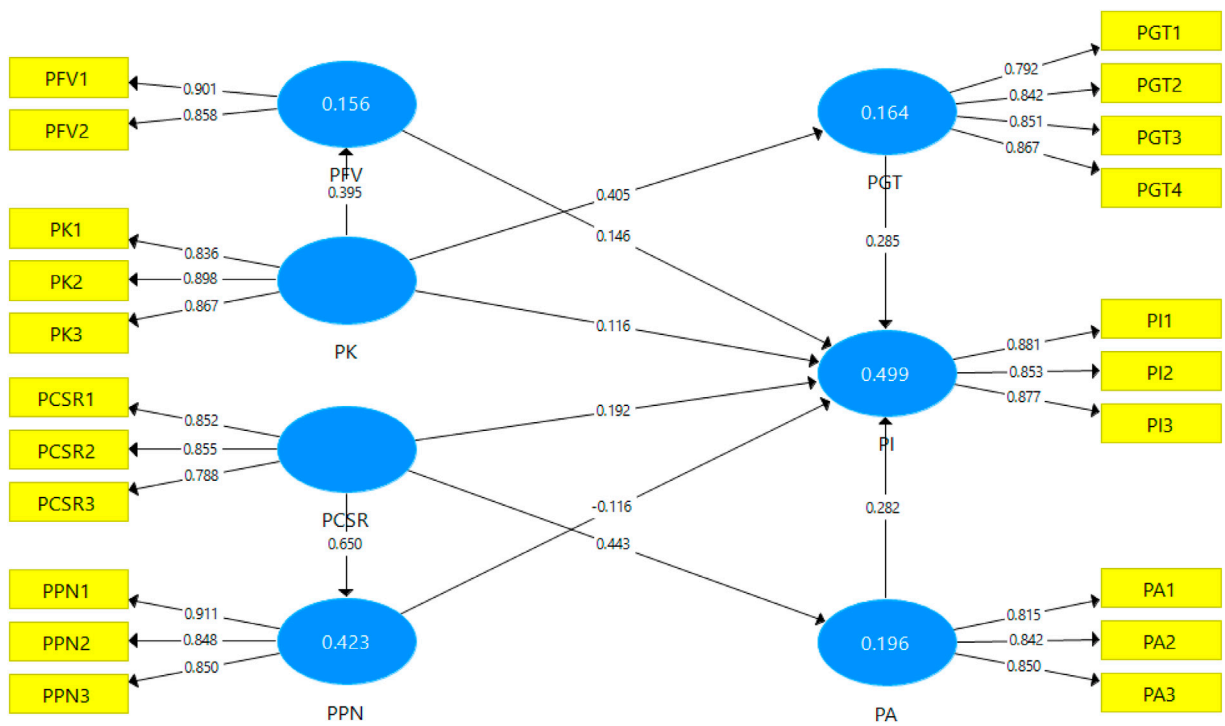

FIGURE 2 | Measurement model.

different shopping malls, students in different public sector universities and family parks in five major cities of Pakistan. Non-probability convenience sampling technique was used to collect data from respondents. Initially a pilot study has been carried out 50 participants. After the pilot study it was found that there is some ambiguity in the statements of questionnaire items and respondents cannot understand properly what actually we want to ask from them. To resolve this issue, we take from two academic experts of consumer behavior studies, they critically study our questionnaire and recommended some changes in the statements of questionnaire items and recommended that number of items should remain. After the revisions

TABLE 2 | Fornell-larcker criterion.

Constructs	PA	CSR	PFV	PGT	PI	PK	PPN
PA	0.836	0.832	0.880	0.838	0.871	0.867	0.870
CSR	0.443						
PFV	0.399	0.408					
PGT	0.522	0.577	0.493				
PI	0.561	0.521	0.476	0.593			
PK	0.300	0.480	0.395	0.405	0.418		
PPN	0.409	0.650	0.406	0.589	0.398	0.410	

Note(s): PK, perceived knowledge; CSR, consumer social responsibility; PFV, perceived functional value; GT, green trust; PN, personal norms; PA, perceived attitude; PI, purchase intention.

TABLE 3 | Heterotrait-monotrait ratio.

Constructs	PA	CSR	PFV	PGT	PI	PK	PN
PA	0.568	0.549	0.629	0.694	0.496	0.475	
CSR							
PFV	0.530						
PGT	0.634	0.703					
PI	0.688	0.642	0.603				
PK	0.367	0.595	0.513	0.477			
PN	0.495	0.787	0.523	0.685	0.461		

Note(s): PK, perceived knowledge; CSR, consumer social responsibility; PFV, perceived functional value; GT, green trust; PN, personal norms; PA, perceived attitude; PI, purchase intention.

recommended by academic experts, we were able to draft final form of questionnaire and started to collect data. The sample size was determined by using proposed criterion of Kline (2015). He suggested at least ten responses per item. We have 23 items in our questionnaire and we need minimum 230 sample size. To increase reliability and validity, 350 questionnaires were distributed to research participants and received back after the given time to fill the questionnaire. Four Ph.D. scholars were selected as volunteers to collect data in multiple locations including shopping malls, supermarkets and universities in five metropolitan cities of Pakistan. After the screening of questionnaires, we found some mistakes and incomplete responses and we excluded 24 incomplete questionnaires from final sample and now the final sample size is 326.

Questionnaire and Measurement

Before drawing the questionnaire items, we studied and undertook a detailed literature review related to all study variables. A total of 23 items were adapted to create the final questionnaire, and these items were divided into seven sections. First, perceived knowledge of eco-labels was measured with three items adapted from Taufique et al. (2017). Consumer social responsibility was measured with three items adapted from Lee (2009). Perceived functional value was measured with three items adapted from the prior study of Sweeney & Soutar, (2001). Green trust was measured with five items and these items were adapted from the past study of Chen & Chang, (2012). Personal norms were measured with three items adapted from the study of Khare (2015). Attitude towards energy efficient appliances was measured with three items and these items were adapted from the study of Taylor & Todd, (1995). Purchase Intention of energy efficient appliances was measured three items developed by Wang Z et al. (2017). All items were measured on a five-point Likert scale.

Common Method Variance

In a survey sample, common method bias is a significant problem. Harman's single-factor test was applied to analyze the common method bias in this research (Podsakoff et al., 2003). As stated by Harman (1976), a single-factor test was established to determine the existence of CMV among constructs. The data revealed that all sample items were classified into 23 distinct factors, with the first component accounting for 39.273 percent of the total variance, less than the proposed criterion of 50 percent. (**Appendix Table A1**). Furthermore, we applied Smart PLS to conduct a thorough collinearity evaluation test. According to Kock (2015) and many other social science academics, this is a relatively efficient and accurate technique (Zafar et al., 2021). All VIF values are well below the recommended threshold of 5, showing that typical process bias is not a problem in our model (Kock, 2015).

Data Analysis

The Smart PLS 3.3.3 software package was employed in this study. PLS-SEM is a multiphase analysis that first evaluates the measurement model and then assesses the structural model (Ringle et al., 2020). The measurement model requirement ensures that only constructs with adequate items loading, convergent validity, composite reliability (CR), and discriminant validity will be considered significant and used in the structural model. The bootstrapping approach evaluates path coefficients and assesses their magnitude in structural model evaluation. Preacher & Hayes (2008) method was employed in terms of mediation evaluation because it is a more specific way for testing mediating effects and is more suited for use with the PLS-SEM methodology (Hayes, 2009; Hair Jr et al., 2014). For data analysis, the PLS-SEM tool has been used in most recent management research studies (Shujahat et al., 2019; Usman Shehzad et al., 2022).

Measurement Model Assessment

The measurement model was subjected to a first-phase assessment in order to establish the constructs' reliability and validity Hair et al. (2016a). During the evaluation of the measurement model, two factors were deleted due to low loadings, and the remaining ones were greater than the recommended value of 0.70. Except for PFV3 and PGT5, all questions were included in the final measurement model. The factor loadings in **Table 1** and **Figure 2** are greater than the recommended threshold of 0.70. Similarly, the AVE and CR of all constructs are equal to or greater than the recommended standards value of 0.50 and 0.70, respectively. This leads to the development of convergent validity and reliability.

TABLE 4 | Effects size, coefficient of determination, blindfolding results.

Constructs	F^2					R^2	Q^2
	PA	*PFV*	*GT*	*PI*	*PN*	*Enogenouse Constructs*	*Enogenouse Constructs*
CSR	0.244	0.185	0.197	0.035	0.732	0.196	0.135
PK				0.019			
PA				0.107			
PFV				0.029		0.156	0.118
GT				0.079		0.164	0.112
PI						0.499	0.361
PPN				0.013		0.423	0.310

Note(s): PK, perceived knowledge; CSR, consumer social responsibility; PFV, perceived functional value; GT, green trust; PN, personal norms; PA, perceived attitude; PI, purchase intention.

TABLE 5 | Hypotheses results.

	Relationships	*Path Coefficient [T-Statistics]*	*p Values*	*BCILL-BCI UL*	*Results*
H1	PK - > PI	0.116 [2.088]	0.037	[0.009, 0.225]	Supported
H2	PK - > PFV	0.395 [7.373]	0.000	[0.288, 0.501]	Supported
H3	PK - > GT	0.405 [8.966]	0.000	[0.318, 0.495]	Supported
H4	PFV - > PI	0.146 [2.719]	0.007	[0.042, 0.252]	Supported
H5	GT - > PI	0.285 [3.158]	0.002	[0.107, 0.455]	Supported
H6	CSR - > PI	0.192 [2.691]	0.007	[0.047, 0.329]	Supported
H7	CSR - > PN	0.650 [17.479]	0.000	[0.575, 0.720]	Supported
H8	CSR - > PA	0.443 [7.347]	0.000	[0.326, 0.560]	Supported
H9	PN - > PI	-0.116 [1.665]	0.096	[-0.243, 0.025]	Not Supported
H10	PA - > PI	0.282 [5.037]	0.000	[0.172, 0.396]	Supported
Indirect Effects					
H11	PK - > PFV - > PI	0.058 [2.413]	0.016	[0.015, 0.109]	Supported
H12	PK - > GT - > PI	0.115 [3.053]	0.002	[0.044, 0.190]	Supported
H13	CSR- > PN- > PI	-0.075 [1.668]	0.095	[-0.159, 0.017]	Not Supported
H14	CSR- > PA- > PI	0.125 [3.863]	0.000	[0.069, 0.197]	Supported

Note(s): PK, perceived knowledge; CSR, consumer social responsibility; PFV, perceived functional value; GT, green trust; PN, personal norms; PA, perceived attitude; PI, purchase intention.

Further, the Fornell–Larcker criteria and heterotrait–monotrait (HTMT) ratios are used to validate the discriminant validity of the current research (Hair et al., 2016a). Using the Fornell–Larcker criteria, **Table 2** shows that discriminant validity has been confirmed since the top value of variables correlations in each column is the maximum (Hair et al., 2016b). The values of HTMT ratios should be less than 0.85 according to the HTMT ratios criteria; nevertheless, ranges up to 0.90 are allowed (Hair et al., 2016a). As shown in **Table 3**, all HTMT ratios are below 0.85, indicating that discriminant validity has been verified for the current research model.

Structural Model Assessment

The findings show that the R2 and Q2 values for PA are 0.196 (Q2 = 0.135), PFV 0.156 (Q2 = 0.118), PGT 0.164 (Q2 = 0.112), PI 0.499 (Q2 = 0.361), and PPN 0.423 (Q2 = 0.310). The R2 values indicate the model's in-sample predictive potential (Sarstedt et al., 2014) since they are more than the necessary threshold of 0.10. Also, Q2 values larger than 0 suggest appropriate predictive relevance. Likewise, effect sizes (f2) are computed to determine the amount to which a predicting (exogenous) variable adds to an endogenous variable's R2 value. The results in **Table 4** demonstrate that the effect sizes of the variables in this study range from small to large, confirming the model's strength (Hair et al., 2016a).

After compulsory evaluation of measurement model, evaluation of structural model test was done in the second phase. Bootstrap resampling technique with 5,000 resamples (Ringle et al., 2020; Gul et al., 2021c) was utilized to establish the significance of direct and indirect paths. **Table 5** lists the test outcomes of hypotheses intended for direct and indirect associations (see **Figure 3**).

First, we assessed the direct relationships before looking at the mediation effects. Results in **table 5** revealed that PK was significantly associated with PI (β = 0.116, p = 0.037), PFV (β = 0.395, p < 0.001), and PGT (β = 0.405, p < 0.001). Therefore, H1, H2 and H3 were supported. Similarly, PFV (β = 0.146, p < 0.01) and PGT (β = 0.285, p < 0.01) were also significantly associated with PI and study results supporting H4 and H5. Moreover, results revealed that PCSR was also significantly associated with PI (β = 0.192, p < 0.01), PPN (β = 0.650, p < 0.001), and PA (β = 0.443, p < 0.001). Therefore, findings confirm

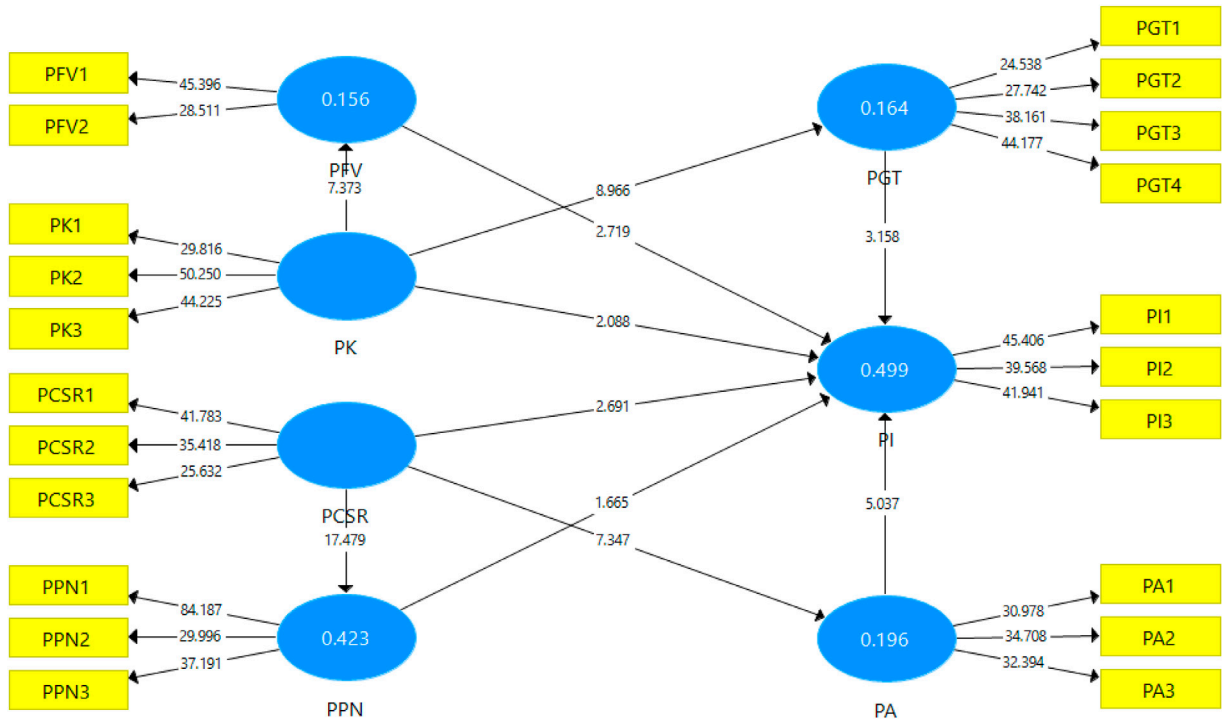

FIGURE 3 | Structural model.

that H6, H7 and H8 were supported. For H9 and H10, study found PPN (β = -0.116, p = 0.096) was insignificantly asscoiated with PI, Whereas PA (β = 0.282, p < 0.001) was significantly associated with PI. Thus, H9 was rejected and H10 was supported.

To test the mediation effect, we used the bootstrapping the indirect effect method (Preacher & Hayes, 2008) with a 5,000 resample. For H11 and H12, Results revealed that PFV (β = 0.058, p = 0.016) and PGT (β = 0.115, p < 0.01) were significantly mediated the relationship between PK and PI. Therefore, results support H11 and H12. Moreover, For H13 and H14, study found insignificant mediating effects of PPN (β = -0.075, p = 0.095) and significant effects of PA (β = 0.125, p < 0.001) in the relationship beween CSR and PI, which do not support H13, while H14 was not supported.

DISCUSSION AND CONCLUSION

In the study, despite strong theoretical grounds for the prediction in previous studies, consumers' purchase intentions for energy-efficient appliances were predicted in Pakistan. In previous studies, the authors examined consumer intentions to buy energy-efficient appliances, but failed to uncover whether consumer perceptions of their social responsibility or personal norms impacted their buying decisions. An investigation of consumer intentions to purchase energy-efficient appliances was conducted using a conceptual framework in this study.

Consumer knowledge of eco-labels impacts green trust and the functional value of products significantly and strongly, as found by previous studies. As a result, eco-label knowledge can contribute to the overall value of a product and establish trust. The finding is consistent with Khare (2015), claiming that consumer social responsibility has a positive impact on consumers' attitudes towards energy-efficient appliances. It was confirmed that consumers' social responsibility influences perceived consumer norms, which is similar to Schuitema et al. (2020). These findings reveal consumers' intention to reduce environmental issues. In addition, consumers' expectations as well as their view of energy-efficient appliances was associated with the intention to purchase them.

Consumer expectations and attitudes greatly influence consumers' choice of energy-efficient appliances, according to Trotta (2018) and Oikonomou et al. (2009). In contrast, previous studies on purchase intention examined the influence of functional attributes on purchase intentions and found the influence to be positive (Orlov & Kallbekken, 2019; Gul et al., 2021d). According to Mazhar et al. (2022), green trust did not have any significant influence on purchase intention, which was reiterated in this study. Consumption of eco-friendly products is not given much importance by consumers because they are skeptical about their functional values. Overall, the results showed that the proposed model is highly applicable to eco-friendly products purchases because its predictive capability is high.

Theoretical Implications

In contrast to previous studies, this study makes significant contributions. Initially, this study presented an antecedent

model for predicting energy-efficient home appliances based on consumer awareness of eco-labels and functional values. It differs from previous studies that have focused primarily on the general understanding of the environment and attitudes toward purchasing energy-efficient appliances (Zhao et al., 2020). The current study focuses primarily on eco-label knowledge. It is a strategic marketing tool to create a positive image about eco-friendly products and to encourage customers to buy them. Additionally, the conceptual model was tested in a developing country (Pakistan). Consumer attitudes toward social responsibility and consumer norms regarding the purchase of eco-friendly products are both important factors in determining whether they will buy eco-friendly products. When eco-label knowledge is combined with consumer perceptions of customer responsibility and consumer norms, the probability of eco-friendly behavior is improved following COVID-19.

Managerial Implications

Researchers have found that home appliances that are energy-efficient are more likely to be purchased by consumers, and their findings can provide marketing and policy makers with guidelines. Promotion and development of energy-efficient products are largely the responsibility of marketers and policy-makers. It is essential to establish a standard for eco-labeling and to strengthen its supervision in the country. Thus, consumers' trust in and decisions about buying energy-efficient appliances are largely influenced by the information on ecolabels (Gahlot Sarkar et al., 2019). It is also crucial for companies to help develop and promote energy-efficient home appliances. Technology innovation and improvements in the efficiency of household appliances are among the key functional values that companies should emphasize, in order to attract consumers to value the surprising energy-saving effects of appliances. By providing information on how to use energy-efficient appliances, eco-label designs could help households save money. In turn, it indicates that functional values are holding people back from buying energy-efficient appliances. Consumer confidence will be built through the use of environmental labeling schemes promoted by policymakers and marketers. Consumers' attitudes and perceptions of consumer's personal norms are influenced by consumers' social responsibility, which supports the significance of environmental values (Abu-Elsamen et al., 2019). Consequently, eco-labels are a good way of making sure consumers are informed about how emissions can be reduced by utilizing energy-efficient appliances. By advertising and marketing campaigns, consumers should also be encouraged to save energy by using energy-saving appliances.

Limitations and Future Research Directions

We have attempted to present a holistic model in this study. Future research should address some limitations. Results may be limited in their generalizability when self-reported data are used. It may be possible for future researchers to evaluate consumers' actual consumption of energy-efficient products by using longitudinal data or by using experimental design. In this study, constructs such as self-identity and altruism were included as potential constructs to predict purchase intention, however many other constructs could also be used. Its focus is on a single country i.e., Pakistan. To increase generalizability, future studies need to include more countries.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2022.863127/full#supplementary-material

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APPENDIX 1 | COMMON METHOD VARIANCE.

Total variance explained						
Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% Of variance	Cumulative %	Total	% Of variance	Cumulative %
1	9.033	39.273	39.273	9.033	39.273	39.273
2	1.800	7.826	47.098			
3	1.588	6.905	54.003			
4	1.320	5.738	59.741			
5	1.035	4.501	64.242			
6	0.932	4.054	68.296			
7	0.812	3.533	71.829			
8	0.772	3.354	75.183			
9	0.647	2.815	77.998			
10	0.575	2.499	80.497			
11	0.545	2.371	82.868			
12	0.494	2.148	85.016			
13	0.459	1.995	87.011			
14	0.427	1.855	88.866			
15	0.404	1.757	90.624			
16	0.356	1.548	92.172			
17	0.316	1.375	93.547			
18	0.297	1.292	94.839			
19	0.280	1.219	96.058			
20	0.257	1.116	97.174			
21	0.242	1.052	98.226			
22	0.214	0.931	99.158			
23	0.194	0.842	100.000			

Extraction Method: Principal Component Analysis.

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Nexus Between Economic Development and Energy Poverty to Gain Energy Efficiency: Empirical Evidence From China

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Mediating the nexus between economic development, energy poverty, and energy efficiency has become a major issue for governments. Evidence from China shows that both sectors have an important role in determining economic development policies and alleviating poverty. Economic development in China is examined experimentally in this research. This study makes use of the Data Envelopment Analysis and the entropy approach between 2007/08 and 2010/11 on the 17 provinces of china. For every unit increase in economic growth pressure, the development indicator of energy efficiency falls by 3.4 percent. Energy poverty and energy efficiency in China are strongly linked to economic development, according to the model's economic development findings. Economic inequalities in China have increased as a result of greater economic development or China's economic development to be of high quality, we believe that our results will be useful in understanding the function of national economic growth management and coordination in wealth distribution and energy use. For rural and male-headed families, the economic development is more consistent. Employees are most likely to be economic developmentt from an increase in economic development, which is expected to reduce energy poverty the most and improve energy efficiency the most.

Keywords: economic development, energy efficiency, energy poverty, DEA, China

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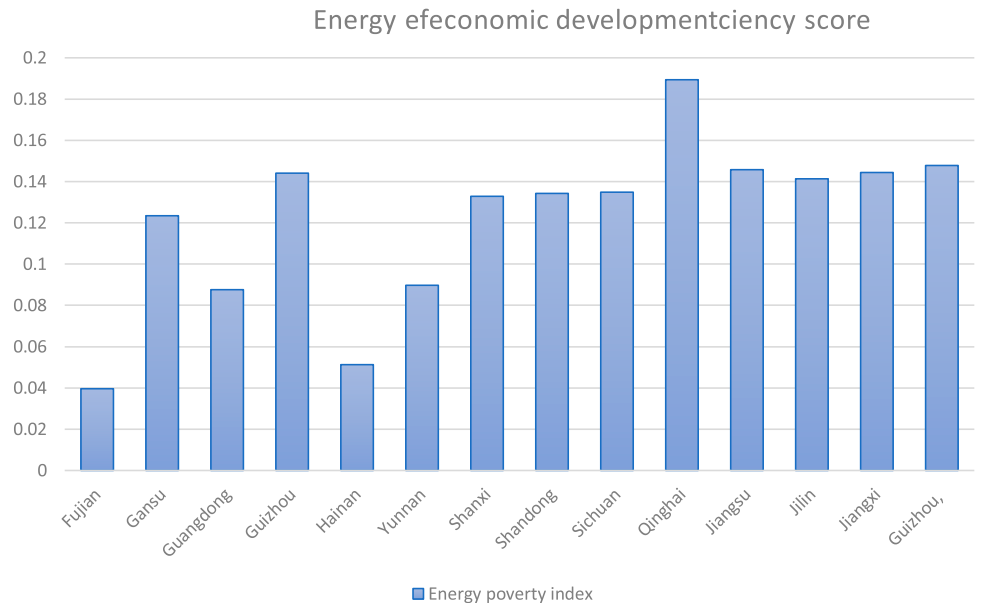
INTRODUCTION

Households with low incomes are more likely to suffer from energy poverty due to the high cost of energy and the prevalence of old, economic development structures. Those problems may be tackled by increasing income, regulating fuel costs, and improving the energy efficiency of buildings (Najmeh et al., 2017). As per the underlying economic circumstances and the economic, administrative and economic plans, rising energy prices have an impact on the earnings of disadvantaged socioeconomic categories. Authorities and institutions have been inhibited by the high cost of thoughtfully designed energy resources, as well as the limited buying power in emerging economies, in their attempts to speed up the shift away from traditional to current energy for cooking and lighting (C. J. P. Chen et al., 1997). Conventional biomass is used by almost 3 billion people



GRAPHICAL ABSTRACT | Energy efficiency of different provinces.

throughout the world to cook their meals. Kerosene is used by 120 million people, whereas coal is used by 170 million people (International Energy Agency [IEA], 2017). About 905 million people in sub-Saharan Africa (SSA) do not have access to clean cooking fuels, and 578 million people do not have access to electricity (IEA, 2020). The high levels of energy poverty in many SSA nations may be attributed to these factors. In nations like Malawi and Madagascar, where data is readily available, energy poverty is estimated to be as high as 98 and 97% of the population, correspondingly (Que and Zhang 2021). For minimal transitioning, China's housing sector accounts for around 25 percent of total energy usage (Black, Harrison, and Baldwin 2010). Energy efficiency and community engagement may be addressed in a unique way via the potential economies of scale and reductions in monetary and social expenses for inhabitants of affordable homes. Even with these obstacles in the way, the affordable housing stock remains afraid of change because of a wide range of factors.

The fundamental technique for reducing energy poverty and is to improve energy efficiency, which is also the prerequisite for sustainable development (Verdelhan 2018). Considerable effort has been made by certain researchers to optimise energy efficiency the conditions of adversity. Numerous optimization techniques are primarily responsible for realising industrial process energy efficiency improvements. Optimization of vapour compression terminal workload using the economic development adaptability approach was performed by (Call, Sharp, and Shohfi 2021). It allows the compressor to run more economic development which cuts down on overall power use. Convolutional networks were utilised by (Farhi and Maggiori 2018) to forecast the optimum operating parameters for the integrated air conditioning system. Later, methodologies were utilised to improve the daily energy-system operation schedule. A long-running argument has surrounded the link between economic development sector expansion and economic growth. When a corporation's economic development rise, they support the expansion of economic circumstances in a society. Therefore, accounting does not generate economic growth but rather responds in order to address the needs of the current sector. (Altman 1968). Furthermore, (Du and Schreger, 2016),and (Acharya et al., 2012) claimed that credit intermediaries that create employment are premises used to examine empirical data.

This is also reinforced by According to this theory, a strong economy encourages the expansion of the economic development industry. Low-income families are particularly impacted by this dynamic, which results in a large loss of social assistance and an unacceptable decline in living conditions. In order to address the issue of energy poverty, short-term appropriate measures must be found, such as balancing tariffs with social spending and direct economic development assistance instruments via energy policy (Allayannis and Klapper, 2003). Because the average consumer demands social and social assistance, such mechanisms cannot address wasteful energy consumption and put pressure on already-tight national or regional economic development. (F. Li et al., 2021).and (Zhang et al., 2021)used the Global Economic development Index (Global Economic development) to examine deposits, credits, banking transactions, and risk management approaches in 149 nations. According to their exploratory study, approximately half of the world's adults have economic development transactions, whereas the other half don't have any. Two-thirds of individuals without a bank account were similarly hampered by high living expenses, remoteness, a lack of records of transaction records, and other issues. This happens across nations as a result of a lack of economic development and a rise in poverty as a result of uneven remittance inflows. This is always characterised by reasonable causes. (X. Wang, Mao, and Li 2021).and (Zhu et al., 2020) argue that families must be ready to spend on contemporary resources before they become more widely

accessible in order to overcome the obstacles of energy poverty and its negative impact on the population. There is a pressing need to examine policy options that might help families migrate to a more sustainable future and eliminate energy poverty in a long-term manner. While macroeconomic stability has been shown to reduce poverty and improve household well-being in general (Kang 2020) (Zheng and Zhao 2020), its impact on energy poverty has yet to be examined empirically at the neighbourhood level. Due to the economic development arrangements of energy poverty caused in public residential properties and now in Continental Europe, these obstacles are prominent. Some student accommodation stock is outdated with regards to energy economic development, and occupants' demographic features vary greatly from those in north-eastern European nations (Gao and Hou 2016). As a result of the economic development crisis of 2008, many people are particularly susceptible to economic development increases in fossil fuel costs (Yin et al., 2012). A third factor has added to the problem's invisibility: mild winters have made it economic development for policymakers to see it until the end of this century. In both 16th century settings, design and technical teams backing programmes have criticised adaptation rules based on nationally standardised user behaviours (Amin, Imtiaz, and Khan 2018), (Jiang et al., 2019) and (Wen, Li, and Gao 2020). Emerging economies aren't the only ones dealing with these issues; advanced economies also have to deal with them. This resolution states that energy poverty has a substantial influence on the effectiveness of healthcare, employment, environmental degradation, agriculture and food security, and broadband services. According to the study's economic development (Li et al., 2020) and (Kong and Yan 2020), the absence of clean, cheap, and dependable energy restricts economic, societal, and employment opportunities and is a major reason why the United Nation's sustainable development objectives have not been met. A lack of knowledge about energy poverty is a major factor in families' limited capacity to get energy and the resulting energy poverty. This is referred to as "energy poverty" because of the inability of developed countries' minimum energy consumption to economic development their households' economic development energy requirements (He et al., 2021).

In a number of ways, our research contributes considerably to the body of knowledge. Between 2007/2008 and 2011/12, researchers in China used DEA and the entropy technique to analyze the relationship between economic growth and energy poverty. Economic development and energy poverty are intertwined, as our research shows, and this link has to be better understood at the national level. It offers a thorough examination of the ways in which energy insecurity affects a country's ability to improve its energy efficiency. As a departure from the traditional emphasis on poor nations, this research explores a new factor that contributes to energy poverty and presents compelling evidence that a developed country, the United States, has a high percentage of energy poverty. Economic development may play an important role in helping to alleviate energy poverty by helping families better manage their energy transitions and so lower their overall energy consumption. These results will be of special interest to policymakers.

The rest of the paper is organized as follows; literature review is presented in **Section 2**. Data and methodology is in **Section 3**. Results and robustness analysis is presented in **Table 4**. **Section 5** contains Conclusion and policy implications.

LITERATURE REVIEW

Neoclassical growth economic theories' influence on economic development and energy poverty has been widely discussed in the last decade (Song et al., 2019). World-wide economic development was acknowledged as one of the eleven pillars of the international development agenda during the high-level meeting in Beijing, China, in 2010. (Wang et al., 2016). Using access to economic development services is an aspect of economic advancement that has attracted a great deal of interest and scholarly attention in the 2000s as a result of study results that linked poverty alleviation to economic development (Wang, Elbery, and Rakha 2019) (Storn and Price 1997). Since it allows families to make long-term commitments, sustain expenditure levels over time, and endure economic shocks, Economic development raises living standards and reduces widespread poverty (Vuković et al., 2018a). The relationship between economic development and family income and poverty has been extensively examined (Aly and Peralta 1999) (Sihwail et al., 2020). It has been concluded by this research that Economic development rises contribute to an increase in income for low-income families. According to Burgess and (Vuković et al., 2018b), an expansion in rural bank branches in India has contributed to a decrease in rural poverty. According to (Zhao et al., 2020), increased economic development reduces the likelihood of a family in China falling into poverty and prevents that home from falling into poverty in the future. According to (Rizzo and Dougherty 1996) a reduction in poverty is associated with a rise in multi-dimensional economic development, which includes having a bank account as well as having economic development inclusion and banking.

The inefficiency of current structures as far as energy conservation is concerned is a second problem. It is estimated that in both countries, 70% of the residential properties were constructed before energy-efficiency standards were implemented to reduce the amount of energy used by structures. As a result, many of these properties lack insulation, heating systems, or heating and cooling, and instead rely on biomass and electricity as their primary energy sources (Asad, Khan, and Krol 2021) (Shao and Er, 2016). Most massive social high-rises were constructed between the 1940s and 1980s, during which time no central heating was installed and there was no motivation for energy efficiency measures until the 2010s, when government objectives moved from new home construction to upgrading structures (Philippe et al., 2021). Fuel poverty and energy poverty are two separate terminologies used to economic development the situation at the European Commission, both in pertinent scholarly articles and internationally recognised documents. As a "narrower notion" of the problem, fuel poverty was coined in Great Britain to describe a household's inability to adequately heat their homes.

The word, on the other hand, was controversial since it solely addressed home heating demands while ignoring all other forms of energy use. On the other hand, the phrase "energy poverty" encompasses all aspects of average household energy usage and

consumption. However, both names are now employed to denote the same broader substance in today's context. Nonetheless, due to its widespread usage in scient economic developmentc literature, the term "energy poverty" will be used for the purposes of this investigation. Energy efficiency is influenced by the cost of energy and the public's demand for energy efficiency (C. Huang and Mayer 1997). When it comes to quantifying energy choice and how it affects economic development, little progress has been made despite the fact that it is a critical factor. For perhaps the economic developments time, we will use cellular automata modelling to incorporate desires for energy efficiency and quantify the influence of such choices on energy economic development. For Asia's growing economies, energy efficiency is of the highest sign economic development in dealing with environmental destruction and global warming on a worldwide scale.

Economic development families' ability to conduct payment information in an energy efficiency and secure manner is enabled by economic development. Greater economic development and suitable credit might possibly encourage household investment in research, wellness, and micro and small businesses, which could create higher employment or professional revenues in the long run (Yan and Minsker 2006). Numerous studies have shown that economic development improves educational, health, and employment outcomes (Mategaonkar and Eldho 2012). If banking services are available and used (Piscopo, Kasprzyk, and Neupauer 2015) households may start their own businesses to earn extra money that can be used for health and education for their families. Spending on children's education, for example, might increase as a result of such expenditures. Households' improved risk management as a consequence of an increase in economic development will also minimise the impact of economic development shocks on children's educational and health outcomes. It is possible that economic development inclusion might facilitate the easy transfer of cash, therefore facilitating the flow of migration, a vital source of wealth for many families in the developing world. The organisations to maintain above are not mutually exclusive, but they may help clarify the trajectory of energy poverty research. It's clear that the European Commission's new effort, the "EU Energy Poverty Observatory," will help tackle the problem of a single economic developmentt. Members of the UN may use it to collect, examine, track, and exchange data on dynamic indices of energy poverty, and it can also be used to aid those countries' measures to overcome it. The organisations to maintain above are not mutually exclusive, but they may help clarify the trajectory of energy poverty research. About 35% of Greek homes are unoccupied or only inhabited for part of the year. Therefore, in those that are either idle or used for limited periods of time, the return on that investment in energy efficiency measures is minimal. The decreased levels of energy efficiency in second and vacation homes may be exacerbated when owners have less incentive to increase their economic development.

DATA AND METHODOLOGY

Data Sources

This study relied on secondary data to accomplish its goals. 17 provinces in China are included, including Anhui, Fujian, Gansu, Guangdong, Guizhou, Hainan, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Qinghai, Shaanxi, Shandong, Shandong, and Sichuan. Sources for the data include, but are not limited to, the National Bureau of Statistics, the People's Bank of China, China's Banking and Insurance Commission (CBRC), and China's National Bureau of Statistics (CIRC). When it came to analysing trends, data from these organisations proved to be the most reliable. Economic development inclusion, economic development, energy poverty, and energy efficiency were the three main components of this study's factors.

Model Specification

Because provinces have large variations in economic development and energy poverty determining methods, they have varying motivations and capacities to target energy savings. Differentiated data on energy sources such as gas and oil should be used in order to provide a clearer picture of the choices for energy efficiency. Because of data restrictions, energy consumption at the municipal level has been approximated by summing data on urban resource consumption and natural gas usage (Luo et al., 2014). Although these economic development deviate from the exact amount of total energy consumed, the energy efficiency derived from them is incorrect. Total energy usage is calculated using a new approach in this article. Since 2005, all levels of government in China have been required to publish associated measures of energy efficiency (energy concentration or the amount of energy concentration reduced) via distribution methods. Despite the fact that only a small number of cities have made these metrics publicly available, the data in this study is gathered by hand and then used to estimate overall energy use. (McKinney and Lin, 1996).provide further information on this strategy.

At this time, the most often used energy efficiency metrics are the efficiency of a single component and the efficiency of all factors together. Energy intensity, which measures energy use as a percentage of gross domestic product, is a common way to gauge a system's single-factor economic development. There are no input elements like capital or labour, nor is there any consideration for the substitution impact between various inputs in energy intensity calculations. Much research has indicated that using energy intensity to gauge energy efficiency has flaws. Assuming that the model is stable, data envelopment analysis is used to estimate its parameters, which does away with the need for a normal distribution. Individual preferences are determined from the above using pricing and production data. That is why the prefc, prefg, and actually performed designations are used for preferences determined from conventional energy source data, respectively. A long-term prognosis for the energy poverty index is derived by comparing the xij I = 1, 2,. . . j = 1, 2,.. with the value of the *j*th extent of the territory or location of the spec economic developmented nation. As shown below, we employed a conventional method to assess the complete index of energy poverty with a constructive objective.

$$x'_{ij} = \frac{x_{ij} - min\left(x_{ij}, \ldots, x_{nj}\right)}{max\left(x_{ij}, \ldots, x_{nj}\right) - min\left(x_{ij}, \ldots, x_{nj}\right)} \quad (1)$$

$$x'_{ij} = \frac{\min\left(x_{ij}, \ldots, x_{nj}\right) - x_{ij}}{max\left(x_{ij}, \ldots, x_{nj}\right) - min\left(x_{ij}, \ldots, x_{nj}\right)} \quad (2)$$

Where x'_{ij} ($j = 1, 2, 3, \ldots, N; i = 1, 2, \ldots N$) the jth metric of the ith province is the standardised value of the jth statistic. The jth estimate of the ith provincial value is calculated by using the following for all provinces:

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{N} x_{ij}} \quad (3)$$

The entropy value of the jth unit of measure is calculated by using the following:

$$e_j = -k\sum_{i=1}^{N} p_{ij}\, ln\left(p_{ij}\right) \quad (4)$$

Where k = 1/Ln(n) > 0; ej ≥ 0.

$$d_j = 1 - e_j \quad (5)$$

Each measurement's value is calculated as follows:

$$w_j = d_j \Big/ \sum_{j=1}^{m} d_j \quad (6)$$

The following is a formula for calculating the EP, or EP index:

$$EPI_i = \sum_{j=1}^{m} w_j \times p_{ij} \quad (7)$$

Measurement of Energy Efficiency

Because provinces have different distributions of natural resources and mining technologies, they have varying motivations and capacities to prioritise energy efficiency in their infrastructure and operations. Based on demographic data on energy sources, such as hydrocarbons, natural gases may therefore be used to separately calculate the indexes of expectations for energy economic development (G. Bin Huang, Zhu, and Siew 2006). Tone's slack-based efficiency assessment in this subdivision is illustrated by the innovation potential with a sign economic development (Mima and Hallett 1999). Let use these comparable vectors for the initial input and intermediate inputs for the evaluation k be x ∈ R^{+}_{mk}, y ε R^{+}_{sk} and z ε R^{+}_{dk} which are in favour of DMU and are in favour of DMU output. Two different economic development: The inventive potential is offered in three separate coneconomic developmentgurations. Consider the fact that pcgdpt is an exogenous variable reflecting per capita GDP are all variables. The formula for preft is known as the conservation equations, while the equation for lept is known as the monitoring variables in the aforementioned model. Assumptions include a zero mean and relate to the dependent variable distribution of the error terms as well as the absence of any serial correlation.

$$PPSstage1 = \left\{ (x, z) \middle| x \geq \sum_{j=1}^{n} \chi_j \lambda_j, z \leq \sum_{j=1}^{n} z_j \lambda_j, j = 1, \ldots, n \right\}$$

$$PPSstage1 = \left\{ (y, z) \middle| z \geq \sum_{j=1}^{n} z_j \mu_j, y \leq \sum_{j=1}^{n} y_j \mu_j, j = 1, \ldots, n \right.$$

Another strategy for tackling endogeneity that has been mentioned is the propensity score matching method (PSM) (Sitnikova et al., 2008).(Terzano et al., 2001) and (Zucconi and Ferini-Strambi 2000) employed the PSM approach to create an average treatment impact on energy poverty, using economic development as the treatment variable (Granger 1969). Due to their superior system and experience, DMUs with network constitutional provisions are better equipped to withstand deported, well-organized units than non-radial DMUs, and they can also withstand amorphous environments because of the PPS of standard response used for DMUk by two different charters of rights and freedoms and the proclamation of frequent extensive would be able to do so. Only a few researchers utilise the agreement concluded to tackle DMUs in a competent position. As a result, the total effect may be altered by the inadequacy of the intermediate trial (Johnstone and Silverman 1997) (S.-J. Chen and Hwang 1992). In order to accurately assess a unit's effectiveness and position, it is vital to take into account its charitable donation to the halfway intake. This paper provides a novel ranking approach for network development discussion of the economic development of the main occurrence. Using this method, we can economic development out what the energy poverty result would have been for a home in the intervention group (which is also monetarily included) if that same population had been placed in the comparison group instead of the theoretical result that would have occurred.

$$r_k = \min\left(\frac{1}{m}\sum_{j=1}^{n}\frac{s_i^-}{x_{ik}} + \frac{1}{D}\sum_{d=1}^{D}\frac{T_d^*}{z_{dk}}\right) \Big/ \left(1 + \frac{1}{D}\sum_{d=1}^{D}\frac{R_d^*}{Z_{dk}} + \frac{1}{S}\sum_{r=1}^{S}\frac{s_r^+}{y_{rk}}\right)$$

$$s.t. \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{ik,} i = 1, \ldots m,$$

$$\sum_{\substack{j=1 \\ j \neq k}}^{n} \mu_j y_{rj-} s_r^+ = y_{rk}, r = 1, \ldots, s,$$

$$\sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j z_{dj=} z_{dk} + R_d^*, d = 1, \ldots, D,$$

$$\sum_{\substack{j=1 \\ j \neq k}}^{n} \lambda_j z_{dj=} z_{dk-} T_d^{*}, d = 1, \ldots, D,$$

$$s_r^+ \geq y_{rk,} r = 1, \ldots s,$$

$$s_i^- \geq 0, i = 1, \ldots, m,$$

$$s_r^+ \geq 0, r = 1, \ldots, s,$$

$$\lambda_j \geq 0, \mu_j \geq 0, j = 1, \ldots, n.$$

An estimation is used to predict the model, which is coherent and an approximation of the prototype when the prototype is stable. While using price and production statistics for coal, fossil fuel, and petroleum products, different individuals are generated from the SSM. We thus designate coal-derived choices as prefc, natural gas-derived choices as prefg, and oil-derived choices as prefo. There are two steps to the diffused Kalman fuzz economic development cation: the system is initialised such that the conventional Median economic developmencan screen it in the second section.

$$max_{s,\lambda}\sum_{i=1}^{m}R_i^x s_i^x+\sum_{r=1}^{s}R_r^g s_r^g+\sum_{f=1}^{h}R_f^b s_f^b$$
$$s.t.\sum_{j=1}^{n}x_{ij}\lambda_j+s_i^x=x_{ij0}, i=1,\ldots,m$$
$$\sum_{j=1}^{n}g_{rj}\lambda_j-s_j^g=g_{rj0}, r=1,\ldots,s$$
$$\sum_{j=1}^{n}b_{fj}\lambda_j+s_f^b=b_{fj0}, f=1,\ldots,h$$
$$\sum_{j=1}^{n}\lambda_j=1$$
$$\lambda_j\geq 0, j=1,\ldots,ns_i^x\geq 0, i=1,\ldots,m$$
$$s_r^g\geq 0, r=1,\ldots,ss_f^b\geq 0, f=1,\ldots,h$$

Additionally, it is important to highlight that it evaluates renewable energy's semi-elasticity in response to a shift in consumer preferences. However, I evaluate the responsiveness of renewable energy consumption to changes in the underlying control factors. The commerce ratio was selected as the endogenous variable because international trade is often used by governments to influence pollution. To put it another way, the use of renewable energy may have an influence on the trade-to-GDP ratio since it reduces pollution. International commerce has a long history of being credited with lowering energy poverty since it permits polluting companies to be relocated to less energy-poor regions. In addition, as renewable energy sources are being used, the requirement to export polluting businesses is lessening. In order to generate a model, a two-step model is used with competent DMUs (10). Preservative models (ADD) in the early phases, followed by the economic development standards in NSBM for the core processes applied, yield the most useful central events (Loomes and Sugden 1982) Observations described in Models (12) and (13) are shown below:

$$\xi=max\sum_{d=1}^{D}R_d+\sum_{d=1}^{D}T_d$$
$$s.t.\sum_{j=1}^{n}\lambda_j x_{ij}+s_{i=}^{-}x_{ik,}i=1,\ldots,m,$$
$$\sum_{j=1}^{n}\mu_j y_{rj}-s_{r=}^{+}y_{rk,}r=1,\ldots,s.$$
$$\sum_{j=1}^{n}\lambda_j z_{dj}=z_{dk}+R_{d,}d=1,\ldots,D,$$
$$\sum_{j=1}^{n}\mu_j z_{dj}=z_{dk}-T_{d,}d=1,\ldots,D,$$
$$s_i^{-}\geq 0, i=1,\ldots,m,$$
$$s_r^{+}\geq 0, r=1,\ldots,s,$$
$$R_d\geq 0, T_d\geq 0, d=1,\ldots D,$$
$$\lambda_j\geq 0, \mu_j\geq 0, j=1,\ldots,n.$$

Then the below model is solved.

$$\eta_k=\min\left(1-\frac{1}{m}\sum_{i=1}^{m}w_i^d\frac{s_i^{-}}{x_{ik}}-\frac{1}{D}\sum_{d=1}^{D}\frac{T_d^*}{z_{dk}}\right)$$
$$\Big/\left(1+\frac{1}{D}\sum_{d=1}^{D}\frac{R_d^*}{z_{dk}}+\frac{1}{s}\sum_{r=1}^{s}w_r^d\frac{s_r^{+}}{y_{rk}}\right)$$
$$s.t.\sum_{j=1}^{n}\lambda_j x_{ij}+s_i^{-}=x_{ik}, i=1,\ldots m,$$
$$\sum_{j=1}^{n}\mu_j y_{rj}-s_r^{+}=y_{rk}, r=1,\ldots,s,$$
$$\sum_{j=1}^{n}\lambda_j z_{dj}=z_{dk}+R_d^*, d=1,\ldots,D,$$
$$\sum_{j=1}^{n}\mu_j z_{dj}=z_{dk}-T_d^*, d=1,\ldots D,$$
$$s_i^{-}\geq 0, i=1,\ldots m,$$
$$s_r^{+}\geq 0, r=1,\ldots,s,$$
$$0\leq w_i^d\leq 1, i=1,\ldots,m, d=1,\ldots,D,$$
$$0\leq w_r^d\leq 1, r=1,\ldots,s, d=1,\ldots,D,$$
$$\lambda_j\geq 0, \mu_j\geq 0, j=1,\ldots,n.$$

over-input is shown as s_i^{-} *and* s_r^{+}, while under-production is depicted as T_d^* and R_d^*.

RESULTS AND DISCUSSION

Energy inefficiency has a sign economic developmentcant impact on the susceptibility of households to energy poverty because of substantial energy losses. Low-income families have received the most economic development from energy efficiency upgrading initiatives so far. Daily consumption has contributed to up to 75% of the total return on investment for these programmes so far. Energy conservation and other environmental advantages are obvious ((Bezak, Brilly, and Šraj 2014). Despite the fact that the study's research participants are regional capitals or higher cities, the organisational levels and competencies of the various cities are highly varied. While regular prefectures have control over provincial capital cities like Guangzhou or Guangxi, province-level municipalities like Beijing and Shenzhen are immediately under the national government (provincial level cities). As a result, these cities are unrivalled in their own right. Because of

TABLE 1 | Variables.

Block	Dimension	Variable indicator	Symbol	Source
Economic development	Dimensions (1) Accessibility	The total number of bank branches is divided by the total number of adults	Economic developmentndexD1	PBC and NBS
	Dimension (2) Availability	Divide the total number of commercial customer deposits by the adult population	Economic developmentndexD2	PBC and NBS
	Dimensions (3) Usability	Credit and savings allocations to the GRDP	Economic developmentndexD3	PBC and NBS
Macroeconomy		Economic growth (percent)	LnGRDP	NBS
		The million RMB education funding is transformed into the natural log	LnEduc	
		Transform the infrastructure investment (in billions of RMB) into a natural logarithm	LnInfrasc	
		Unemployment (percent)	Unemp	
Poverty and Inequality		Poverty level (percent)	POV	
		Gini Index (index)	IGini	

Source: Processed Data, 2016.

their uniqueness, provincial capital cities also have a higher EGT than other prefecture-level cities. Consequently, these cities are removed from the regression dataset and only the remaining cities are included. The economic development in column (7) are consistent with those found in column (6). The predicted economic development is still 0.033, and it is sign economic development at a 1% level. Overall, the estimate economic development show that growth pressure has a negative influence on energy efficiency improvement, which is lower by 3.3% for each unit of growth pressure. The balanced statistics score is shown in **Table 1**, while the energy efficiency score is shown in Economic development. Consequently, no indication of multivariate regression can be found because of the model's poor pair correlation. With no economic development rules in place, it is predicted that it would be quite diseconomy developmentcult for low-income families to maximise at least 10%, or up to roughly 25%, of sign economic gains gains without removing barriers to energy efficiency.

Column 1 shows that each rise in economic development is associated with a 0.083-standard-deviation fall in family energy poverty. When economic development is increased by one standard error, family energy poverty is reduced by 0.092 and 0.061%, respectively. In other words, our combined data is in line with the economic development that were gleaned from each of the survey's distinct rounds. This study's economic development suggest that economic development may help reduce energy poverty in the home as a whole. For a long time, EGT management has been extensively used in many economies all over the globe. China, India, and the United Kingdom are only some of the industrialised and emerging nations that have disclosed or continue to announce economic development objectives since 1950. There has been research on the impact of economic growth management on various aspects of economic development, but these studies have been heavily focused on China's economic predicament.

Additionally, the savings and insurance features of economic development aid in smoothing families' usage of contemporary and easier-to-clean fuels and technologies. Previous research has found that economic development inclusion has the ability to alleviate energy poverty (Buttle et al., 2016). The long-run development prospects of the main energy-producing and consuming nations are evaluated using the economic models listed below. An indicator of energy poverty is used to estimate social wellbeing in the research sample nations using growth regression. In this connection, it's important to note that renewable energy sources play an important role. Renewable energy sources are projected to have a positive impact on green funding, and all the sample nations indicate a substantial association between the variables. A considerable role is played by green economic development approaches and renewable energy sources in the process of environmental clean-up and greening. The growth hypothesis is supported by the economic development, which suggest a one-way causal link between energy poverty and social well-being in the study's surrounding nations. However, the implementation of novel energy solutions for energy efficiency has an indirect impact on regional economic development.

Economic development increases of one variance are connected to a 0.083 standard deviation drop in family energy poverty in Column 1. An increase in economic development by one error margin in Columns 2 and 3 reduces family energy poverty by 0.092 and 0.061 statistical economic development, respectively. In other words, our pooled data seems to be in agreement with the outcomes predicted by separate rounds of the survey. Overall, our economic developments show that economic development has a direct impact on reducing family energy poverty. Another study found that the impacts of economic development independence on household energy poverty are more pronounced than those of other factors such as a person's age, gender, or marital status. An explanation for the result might be that economic development offers the resources necessary for families to get safe, high-quality energy services. Additionally, the savings and insurance features of economic development aid in smoothing families' usage of contemporary and cleaner cooking fuels. The ability of economic development to alleviate energy poverty has already been shown in previous research (Basu and Srinivas 2015).

2SLS regression is computed using our distance to the bank instrument as a proxy for endogeneity (see **Table 2**). As predicted, the economic development stage economic development show

TABLE 2 | Weighted data.

DMU	VX (1) EC	VX (2) Labor	UY(1) EP	UY(2) GDP
Anhui	0.00	1.00	0.08	0.38
Fujian	0.84	0.11	0.79	0.14
Gansu	0.00	1.00	0.06	0.01
Guangdong	0.94	0.01	1.00	0.00
Guizhou	0.00	1.00	0.03	0.15
Hainan	0.8	0.017	0.32	0.04
Yunnan	0.00	1.00	0.09	0.07
Shanxi	0.00	1.00	0.06	0.56
Shandong	0.51	0.61	0.91	0.21
Sichuan	0.87	0.12	0.32	0.00
Qinghai	0.88	0.11	0.41	0.05
Jiangsu	0.00	1.00	0.07	0.04
Jilin	0.42	0.74	0.24	0.84
Jiangxi	0.65	0.74	0.61	0.04
Guizhou	0.45	0.56	0.74	0.02
Hainan	0.54	0.59	0.55	0.07
Heilongjiang	0.39	0.61	0.47	0.09

TABLE 3 | Energy poverty index score.

Province	Energy poverty index
Fujian	0.03962143
Gansu	0.12345987
Guangdong	0.087625
Guizhou	0.1440976
Hainan	0.0512876
Yunnan	0.0897549
Shanxi	0.1328744
Shandong	0.1342875
Sichuan	0.1348754
Qinghai	0.18937547
Jiangsu	0.14578468
Jilin	0.14135845
Jiangxi	0.1444191
Guizhou	0.1478224

that a greater distance from the closest bank resulted in a decline in economic development (Columns 1–3). If economic development is the F-statistics are all more than 10, which shows that our instrument has a strong association with this variable in these models, comparable with (Gado and Nguyen, 2016). To indicate a weak association, the F statistics in Columns 1 and 2 of Panel C (e.g.) were less than 10 (e.g.). Our finding addresses this issue. Based on the endogeneity of economic development, we may conclude that our baseline estimations have a lower bias because of this. When compared to industrialised nations, China's marketization level is still relatively low in the current stage of economic change. As a result, the macroeconomic effects of EGT management, a government intervention, should be examined. Is economic growth pressure a significant factor in reducing energy efficiency? Is there a varied effect depending on the situation? Existing research, however, fails to address these issues. This work aims to fill the void left by this lack of research. The pressure to sustain economic growth is also measured by the gap between the goal and the correct data on growth in the economy (). This puts additional pressure on organisations to sustain growth if the EGT differential is energy efficiency enough. **Table 3** shows the estimated economic development in columns (5) and (6). There are estimated of 0.06 and economic development at the 1% level, which indicates that the larger the greater is less favourable to energy efficiency development. The rationale is obvious. To keep the economy growing, the government has a strong incentive to increase the amount of energy it uses. Pressure to expand may lead to an increase in the amount of energy used. It is clear from the economic development of the better strength and key explanatory factors that the benchmark results are reliable.

Almost all of the population living in the sample nations is Roughly 1.5 billion people were involved in the aggregate and aggregate gross domestic product of around $6.5 trillion between 2016 and 2018. A 0.1% increase in future economic development may result in a 1% increase in energy economic development, thanks to the use of sustainable power. Results backed by prior research, such as the importance of a low-carbon future in economic growth and energy poverty, on energy efficiency (Douglas, Vogel, and Kroll 2000). **Table 4** econometric approach is used in our research to demonstrate outcomes for environmental function and growth function. According to the economic development, social wellbeing is more elastic in regions with high levels of energy poverty.

Data on econometric estimates is shown in **Table 3**. **Table 4** is a measure of social well-being. In recent years, environmental equality has been a major issue for domestic and international governments (Ouarda et al., 2008). There are just 35.8 percent of Pakistan's 155 localities with air quality that is near to population quality guidelines that represent 55.4 percent of the country's geographical area, according to the Pakistan Effective Environmental Weekly (2018). A comparison of energy education and infrastructure wellbeing in emerging countries shows that these nations are susceptible to climate change. National infrastructure and societal well-being are negatively impacted by climate change vulnerability. These occurrences exacerbate the problem of energy poverty. Over 40% of the population of Pakistan suffers from energy shortages, and power supply losses are as high as 30% of the country's energy consumption (Önöz and Bayazit 2012). In the last decade, Pakistan has witnessed catastrophic flooding on a regular basis. 2010s devastating flooding killed 1,876, wounded 3,098, and demolished more than 1.89 million homes. At the time of the 2011 flood, more than 5.3 million people were impacted, and more than 1.7 million acres of agricultural land were submerged (El-Jabi et al., 2016).

Robustness Analysis

Energy poverty may be addressed in a variety of ways, and **Section 2** explores a few of these possibilities. Structures for analysing the feasibility of economic development and energy efficiency projects are the same in all circumstances. This would appear to bolster the second finding. It has been earlier used by (Durocher and Jean François, 2017) (K. Huang et al., 2018) As a preliminary step, we demonstrate that economic development has a strong relationship with consumer poverty and per capita family income. A standard deviation rise in economic development is followed by a 0.114 standard deviation drop in economic impoverishment, according to **Table 5**. Our models

TABLE 4 | Economic development and energy poverty.

Energy poverty	(1)	(2)	(3)
	Pooled	GLSS6	GLSS7
Panel A: Full Sample			
Economic development	−1.123***	−1.154***	−1.303***
	(0.154)	(0.198)	(0.303)
	[−1.454]	[−1.332]	[−1.606]
Household head characteristics	Yes	Yes	Yes
Household variables	Yes	Yes	Yes
Year economic development effects	Yes	No	No
Regional economic development effects	Yes	Yes	Yes
Economic development-Stage			
Distance to the nearest bank (km)	−0.003***	−0.004***	−0.006***
	(0.002)	(0.002)	(0.001)
F-statistic of economic development regression	69.87	49.09	21.09
Observations	18,575	13,487	5,875
Panel B: Rural Sample			
Economic development	−0.322***	−0.332***	−0.222**
	(0.039)	(0.051)	(0.154)
	[−0.505]	[−0.632]	[−0.611]
Household head characteristics	Yes	Yes	Yes
Household variables	Yes	Yes	Yes
Year economic development effects	Yes	No	No
Regional economic development effects	Yes	Yes	Yes
Economic development-Stage			
Distance to the nearest bank (km)	−0.004***	−0.004***	−0.005***
	(0.002)	(0.002)	(0.002)
F-statistic of economic development regression	112.67	89.67	11.45
Observations	11,634	8,532	3,421
Panel C: Urban Sample			
Economic development	−3.658	−2.196	−2.642***
	(3.654)	(0.864)	(0.965)
	[−3.675]	[−3.954]	[−2.422]
Household head characteristics	Yes	Yes	Yes
Household variables	Yes	Yes	Yes
Year economic development effects	Yes	No	No
Regional economic development effects	Yes	Yes	Yes
Economic development-Stage			
Distance to the nearest bank (km)	−0.001	−0.001	−0.007***
	(0.001)	(0.001)	(0.002)
F-statistic of economic development regression	0.39	2.45	11.35
Observations	8,755	6,785	2,523

TABLE 5 | Effect of economic development on energy poverty.

Variables	(1)	(2)
	Poverty	log (household net income)
Economic development	−0.112***	0.521***
	(0.004)	(0.021)
	[−0.121]	[0.171]
Household head characteristics	Yes	Yes
Household variables	Yes	Yes
Year economic development effects	Yes	Yes
Regional economic development effects	Yes	Yes
Observations	21,763	19,542
R-squared	0.321	0.267

haven't altered, but they certainly should, since RE offers new hazards not present in baseload capacity plants, on which our models are built." "In the beginning, we employed distinct sets of frameworks for analysing conventional power project bids and RE project ideas,"

It was only through time that [our bank] was able to merge all of these different frameworks used in appraising power projects into a single one, regardless of the technology, he writes. As a result, "the assessment criteria were integrated into a single framework due to discovered overlaps." As a result, it seems that banks' sales efforts

TABLE 6 | Energy efficiency Score in provinces.

Province	Energy efficiency
Anhui	57.16167
Jiangsu	56.52648
Shanxi	54.25847
Shanghai	55.41684
Fujian	54.65284
Hunnam	56.16524
Zhejiang	54.15394
Shandong	54.36941
Yunnan	56.45874
Jilin	55.26147
Austria	54.95415
Hainan	55.61478
Guizhou	54.36145
Guangdong	54.49452

TABLE 7 | Effect of Economic development.

Variables	*Dependent variable: Energy poverty*		
	(1)	(2)	(3)
Panel A: Main results			
Economic development inclusion	−0.071***	−0.072***	−0.063***
	(0.004)	(0.004)	(0.004)
	[−0.069]	[−0.087]	[−0.071]
Poverty		0.034***	
		(0.003)	
		[0.034]	
log (household net income)			−0.039***
			(0.001)
			[−0.123]
Observations	21,018	21,018	19,232
R-squared	0.245	0.246	0.278
Panel B: Consistency check			
Economic development inclusion			−0.071***
			(0.004)
			[−0.089]
Observations			21,018
R-squared			0.242

and quotas have been influenced more by the relentless pursuit of sustainability goals than their credit frameworks and methodologies. Ohers was interested in sustainability only as an afterthought. In recent years, some banks have lent money to renewable energy projects, while others have just a few RE loans in their portfolio. If our original premise (see is correct, banks will be more willing to fund small-scale renewable energy projects, especially merchant plants from small RE developers. Our goal is to validate this theory. The re-estimated models show that adding household net income as a economic development of multiple determination reduces the size of the economic development. Therefore, consumption poverty and family net income are key economic development-energy poverty routes.

CONCLUSION AND POLICY IMPLICATION

Economic development has had a long-term influence on the economic development industry. But few studies have compared it to economic development. In that context, this study examined the influence of economic development on energy efficiency, as well as the impact of poverty reduction measures. The influence of economic development on energy poverty, and energy efficiency in 17 Chinese provinces between 2007/08 and 2010/11 is examined. Despite several worldwide efforts to eliminate energy poverty, the issue persists, with the prevalence greater in poorer nations. The economic development-energy poverty nexus has gotten little attention despite its potential to contribute in this struggle. The few research that exist on this issue do not use a multidimensional economic development. The GLSS6 and GLSS7 data were used to assess the influence of economic development on domestic energy poverty. Endogeneity of economic development is handled through bank distance. We also examine how economic development may affect household energy poverty. We discover: (1) The need for economic expansion has hampered energy efficiency (**Table 6**). Each unit of economic growth pressure reduces the improvement index of energy efficiency by 3.3 percent. And it's true. No energy efficiency changes are detected when fundamental independent variables are replaced.

In model 1, more economic development inclusion reduced poverty (**Table 7**). So, by supplying money, the economic development sector may help reduce poverty. Moreover, the econometric analysis panel's IRF economic development revealed a favourable beginning phase followed by a negative and steady term. In model 2, economic development inclusion reduces inequality. So, the income distribution is more equal. However, the third dimension has a economic development reaction. According to the econometric estimation study, economic development inclusion has a considerable influence on energy efficiency in China. On the other hand, the second and third aspects of economic development inclusion had no effect on unemployment in model 4. The economic development feature, economic accessibility, has a influence on unemployment. The unemployment rate rises with economic development services and availability. Because a transition in the economic developmentn sector from labour-intensive to highly capital-intensive may raise joblessness.

Overall, economic development reduces family energy poverty, and this result is robust to other quasi-experimental methodologies. It also stands up against alternate weighing methods for economic development and multifunctional energy poverty, as well as renewable power poverty cut-offs. Rural family's energy efficiency more from economic development's potential to eliminate energy poverty than urban ones. economic development also reduces energy poverty in male-headed families. Our data suggest that consumption poverty and family net income are key economic development -energy poverty pathways. Other measures aimed at increasing family net income per capita and reducing consumption poverty may support one other to successfully relieve energy poverty. Another policy option is for economic development system authorities to put in place arrangements that minimise the distance travelled to banks. This study shows a favourable association between economic

development inclusion and economic development, but a negative energy efficiency relationship with inequality and poverty. Here are some ideas for improving research contributions in economic development inclusion: Contrasting socio-cultural levels; illiteracy rates; regional interests; gender disparity; income; and government policies. For more inclusive economic development, non-economic elements must be addressed. Other measures aimed at increasing family net income per capita and reducing consumption poverty may support one other to successfully relieve energy poverty. Another policy option is for economic development system authorities to put in place arrangements that minimise the average distance to banks.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

MA: conceptualization, writing-original draft ZY: supervision, data analysis SA: writing Review, data analysis SA: data analysis, writing-original draft MA: proofreading, writing-original draft.

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How Does Energy Efficiency Mitigate Carbon Emissions Without Reducing Economic Growth in Post COVID-19 Era

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A comprehensive analytical study to assess the performance level of industrial functions in the environment has become necessary at the present time. According to existing research, the COVID-19 pandemic resulted in a significant reduction in carbon emissions in 2020. Policymakers are focusing on the discrepancies and negative environmental effect caused by various industries during their routine operations. This study aims to estimate the performance level of energy in the context of the environment of the countries that are members of the European Union This evaluation is performed through a data envelopment analysis (DEA) model, through which we have applied a non-proportional adjustment, taking into account the input of energy and its undesirable output. The DEA model allows dynamic assessment of sources in the field of measuring energy efficiency and its environmental effects. The score of measurement of efficiency lies between zero and one, which means China and Russia are awarded this score of one (1), which shows the highest level of efficiency in clean energy, while Bangladesh (0.19), Uzbekistan (0.09), Mongolia and Cambodia (0.06), and Kyrgyzstan (0.04) are at the lowest level of performance in clean energy. The results of the study showed that clean energy efficiency levels increased in all countries over the study period. The emission level of greenhouse gases in the first world countries was found to be better in the context of improvement in performance enhancement in the sector of the energy mix. Evasion score is measured as 365 kt of CO_2. This score for NO_2 is 280 kt and for SO_2 is 82 kt, whereas it is 23 kt (0.24 kg/cap) of particulate hazardous matter. The higher performance level of energy yields a negative relationship with emissions of gases, with a significant number of 12% for NO_2 in 2000, as compared to 13% for SO_2 and 14% for PM2.5. Whereas PM10 has the highest concentration (18%). Public policymakers may enhance the facilitation system for better free trade and a result-oriented corporate environment to enhance the performance level of energy in the electric sector.

Keywords: energy efficiency, technology, economic growth, DEA, COVID-19

INTRODUCTION

The COVID-19 pandemic shocked the global economy and caused a severe impact on public health. Furthermore, the COVID-19 outbreak had a significant impact on the environment, particularly on carbon emissions (Li et al., 2021). The sustainable increase in temperature of up to 1.5°C is to be maintained in the effective removal of external contributing factors to climate change on the performance of the energy sector for the end-user (Yumei et al., 2021b). The maintenance of this sustainable growth in temperature has been focused on by the "IPCC Special Report on 1.5°C" in which this target sustainable temperature is to be achieved up to the maximum at the end of the present century (Babaranti et al., 2018; Barua et al., 2020; Hou and Xu 2020; Iqbal W. et al., 2021; Cai et al., 2022). Along with the reduction in negative effects of climate change, the high-performance level of energy also brings positiveeffects, a protected supply of energy, and higher competitive advantages in the business sector as well as in the welfare of the public (Khokhar et al., 2020; Irfan et al., 2021; Madurai Elavarasan et al., 2021; Mani et al., 2021; Tanveer et al., 2021). The reduction in demand for energy and enhancement of energy performance has been suggested by the EU, including by all EU member states in the last 30 years (D'Agata et al., 2019; Mahmood et al., 2019; Kong 2020; Rahman and Islam 2020; Rao et al., 2022). The effective mitigation of climate change was set in 2007 as a target to be achieved by 2020 by the European Union. The goal was to reduce GHG emissions by up to 20% from 1990 (Irfan et al., 2019a; Rehman et al., 2021; Yang et al., 2021). The same target of twenty percent was set for renewable energy as well as for low demand for energy (Fu et al., 2021). In the meanwhile, the EU revised these targets for energy consumption and its efficiency in 2014, setting the goals for 2030 (Latif et al., 2021). These revised 2030 EU goals named as the "EU Climate and Energy Target for 2030" includes the reduced level of emission of greenhouse gases up to forty percent of the level in 1990, twenty-seven percent consumption of renewable energy, and the same share (27%) for the higher performance level of energy (Zhang et al., 2021).

Higher energy performance levels are a historically proven factor for cost efficiency and an effective indicator of reduced energy consumption and reduced greenhouse gas emissions (Yumei et al., 2021a). There is a need for time to clarify the concept of the relationship between the efficiency of energy and the level of energy savings (Iqbal et al., 2019). This technical relationship is to be evaluated with an understanding of the degree of possibility of energy savings and endogenous variables of price and income to have autonomous as well as guided impact in the energy efficiency model (Iqbal S. et al., 2021). The demand and supply accepting the effect of such a relationship, resettle the intersection point through which economic activity is reshaped (Abbas et al., 2021). The main aim of this study is to understand the nature of the bounce-back effect of the relationship between energy savings and that of efficiency (Hou et al., 2019) and this relationship is viewed from both perspectives such as actual delivery of savings in the energy sector and adjustments of this change over time.

Primarily the use of energy in its own sector accepts the effect of a higher level of performance of energy in the following ways (Anser et al., 2020). Firstly it is due to the available substitution ways of energy production which are measured in efficiency units in the set predefined target sector (Chien et al., 2021). It brings a cost reduction, and subsequently, prices shift downward due to their measurement in terms of efficient energy (Mohsin et al., 2021). It depicts that the performance level of this sector is greater than the compared consumption level when it is measured in natural units. The second reason for the impact of the efficiency of energy on its use is the level of its competitiveness as per its competitive advantages. Due to efficient energy production, the cost is reduced, which results in prices also reducing. When prices are reduced, demand is increased (Mier and Weissbart, 2020). When there is an increase in demand for energy, obviously there is an increase in demand for its generation. This driven demand of associated goods is firstly due to substitution, and secondly due to the competitive advantages; both of these reflect rebound effect due to which the value of efficiency increases at increasing rates (He et al., 2020; Liu et al., 2021).

Most of the time, the traditional model of analysis related to the efficiency of energy and the environment presumes that the production sector works in perfect competitive condition (Yu et al., 2021). However, this assumption is weak because several variables cannot be easily disposed of in the production sector. Regional efficiency intactness related to energy and environment is highly influenced by two inevitable factors: production sector efficiency is restricted by other sectors, and variable interconnectivity to the production sector. The rationale of this study is to fill the above-mentioned research gap. This study investigated how energy efficiency tends to favor low carbon emissions, given the onset of the COVID-19 pandemic, without reducing economic growth. We have applied the multiplicative function approach to check the interactivity among the variables. Moreover, we have used a modified form of the DEA model, followed by (Zhou et al., 2019) to address the dynamic evaluation of efficiency related to energy and the environment of the Asia Pacific region. Furthermore, this research study has included data envelopment and discriminant analysis (DEA-DA) that is applied to the classification and evaluation criteria of ranking among the firms related to energy, Therefore, this approach is used here in order to determine which countries are efficient and inefficient.

LITERATURE REVIEW

Data Envelopment Analysis

Farrell, (1957) propounded and floated the efficiency concept, which was followed by (Charnes and Cooper, 1984) who used linear programming to measure efficiency scores through a framework of multi-factor production called the DEA model. With the passage of time, many research experts modified this model and applied it to various sectors. The DEA-CRS model, which is also called the CCR model, focused on a constant return to scale, was incorporated (Kopp, 1981). (Banker et al.,

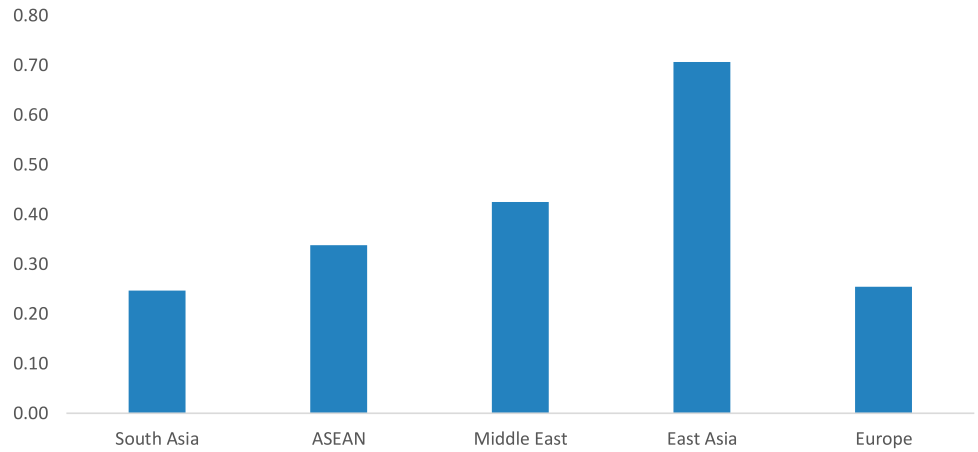

FIGURE 1 | Energy efficiency score.

1984) transformed and developed DEA-VRS to address variable return to scale, which is also called the BCC model. Following this, DEA has been widely used to measure a DMU's production efficiency. Jin-Li and Shih-Chuan (2006) introduced a DEA model application to calculate disaggregate deficiency by focusing on the estimation of energy efficiency of the total factor. Numerous research studies have been conducted by using this method (Wang and Hu 2006; Wang et al., 2019; Zhang et al., 2020). The existing literature also emphasized ecological or environmental energy efficiency, particularly (Banker et al., 1984; Thrall 2000; Zhou et al., 2006; Zhou et al., 2007; Chen et al., 2016), used the DEA energy and environmental index by studying its dynamic nature to measure change and its magnitude in energy production. There are two important components of this method of energy measurement, which are parametric Stochastic Frontier Analysis (SFA) and non-parametric Data Envelopment Analysis (DEA). The DEA approach is based on mathematical programming, while the SFA is related to econometric techniques. Furthermore, (Honma and Hu 2014), included 14 industrial countries in an estimated comparison of performance in industrial energy efficiency in Japan. Furthermore, Makridou et al. (2015) investigated the performance of efficiency in energy-intensive 23 industrialized European countries. (Jebali et al., 2017). analyzed the energy efficiency stages of Mediterranean countries by using the double bootstrap approach of DEA. Gómez et al. (2017) used the bootstrap DEA technique to compare efficiency situations in European countries.

TABLE 1 | Descriptive statistics.

	Labor	EC	CO_2	GDP
Max	1364270000.00	17926.72	45.42	10439.00
Min	1152309.00	222.22	0.28	7.34
Average	88515784.02	2820.17	6.98	471.50
SD	261500201.90	3098.55	8.01	1506.91

However, there are some limitations to calculating energy efficiency mentioned in the literature; likewise, government institutions contribute to energy efficiency proportion. Government institutions have strong machinery and are resourceful in enforcing policies. Energy policies are successfully formulated and implemented by the government to increase energy efficiency, which consequently plays a role in shaping the energy consumption patterns of citizens. Institutional efficiency depends upon enforcing policies. A substantial amount of research has been conducted to investigate the role of government policies on energy, policies that drive energy transition, high energy potentials, and commercial applications of energy technologies such as (Choi et al., 2012; Wang J. et al., 2017; Cheng et al., 2019). However, throughout these research studies, governmental institutional efficiency to improve the energy efficiency gap has been lacking. We have taken up this issue to incorporate a new dimension in this arena of energy efficiency.

Energy Efficiency Techniques

Evaluation of economic development and environmental sustainability are the cornerstones of assessing new technological avenues or processes. It is so because mitigation of climate change affects demand for policies and mechanisms to control pollution generated from fossil fuels. A transition from fossil-based sources of energy to renewable energy sources is an important dimension (Zhou et al., 2012; Wang H. et al., 2017). Bampatsou and Halkos (2019) found the energy efficiency possibility of G7 areas, while refined water supply and renewable sources of energy are very imperative. Energy security and the supply of energy without discontinuity are also paramount to sustainable economic development (Blum 2015).

As interest in energy is quickly developing, in this manner, the emanation of air contamination is quickly expanding. Improving energy effectiveness prompts proficient asset assignment and contributes emphatically to local air quality and natural

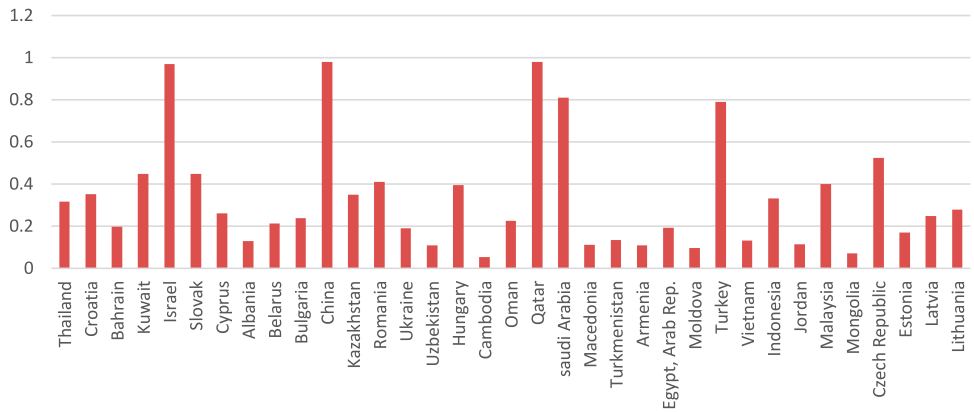

FIGURE 2 | Regional energy efficiency score.

TABLE 2 | Energy efficiency score.

No	Country	2010	2011	2012	2013	2014
1	Thailand	0.35	0.37	0.35	0.33	0.30
2	Croatia	0.22	0.39	0.22	0.33	0.33
3	Bahrain	0.05	0.15	0.05	0.18	0.18
4	Kuwait	0.17	0.45	0.17	0.45	0.42
5	Israel	0.54	1.00	0.54	1.00	1.00
6	Slovak	0.25	0.46	0.25	0.42	0.42
7	Cyprus	0.11	0.27	0.11	0.25	0.24
8	Albania	0.12	0.13	0.12	0.12	0.12
9	Belarus	0.16	0.19	0.16	0.21	0.21
10	Bulgaria	0.15	0.22	0.15	0.20	0.20
11	China	1.00	1.00	1.00	1.00	1.00
12	Kazakhstan	0.29	0.33	0.29	0.35	0.33
13	Romania	0.34	0.38	0.34	0.38	0.40
14	Ukraine	0.19	0.18	0.19	0.19	0.19
15	Uzbekistan	0.09	0.08	0.09	0.10	0.09
16	Hungary	0.38	0.43	0.38	0.39	0.38
17	Cambodia	0.06	0.07	0.06	0.06	0.05
18	Oman	0.10	0.23	0.10	0.24	0.24
19	Qatar	0.19	1.00	0.19	1.00	1.00
20	Saudi Arabia	1.00	0.96	1.00	0.88	0.79
21	Macedonia	0.05	0.10	0.05	0.10	0.10
22	Turkmenistan	0.06	0.10	0.06	0.12	0.12
23	Armenia	0.08	0.10	0.08	0.10	0.10
24	Egypt, Arab Rep	0.23	0.22	0.23	0.21	0.19
25	Moldova	0.07	0.07	0.07	0.08	0.08
26	Turkey	0.84	0.88	0.84	0.86	0.78
27	Vietnam	0.14	0.13	0.14	0.14	0.13
28	Indonesia	0.39	0.43	0.39	0.37	0.34
29	Jordan	0.13	0.13	0.13	0.13	0.13
30	Malaysia	0.41	0.41	0.41	0.38	0.39
31	Mongolia	0.04	0.08	0.04	0.07	0.07
32	Czech Republic	0.38	0.65	0.38	0.52	0.50
33	Estonia	0.06	0.16	0.06	0.16	0.16
34	Latvia	0.13	0.25	0.13	0.26	0.25
35	Lithuania	0.15	0.30	0.15	0.31	0.29

supportability (Blum and Okwelum 2018). Even though interest in inexhaustible wellsprings of energy, for example, wind and Sun, adds to the monetary results, the fundamental concern is the greater expense of power creation from sustainable power sources. The fundamental advance in examining the natural issues confronting organizations or actualizing new ecological arrangements is perceiving business tasks in terms of energy and effect. Then again, to handle the ecological concerns, arrangement producers, for the most part, dispense higher expense rates on natural outflow credits (Sueyoshi and Goto 2017). Concentrating on a financial market, two kinds of markers exist at the full-scale level (Irfan et al., 2019b; Hao et al., 2021; Rehman et al., 2021).

The first and more generally used marker is energy gross domestic product proportion, also referred to in writing as energy power. This estimation technique for productivity depends on solitary information sources, for example, energy utilization, and disregards other significant data sources like capital and work (Sueyoshi et al., 2017). Such indicators are most likely oversimplified and easily distorted in the investigation of overall energy effectiveness (Iftikhar et al., 2018) and, as such, are regarded as a less precise measure for establishing a national or global energy strategy. In this examination, we utilized the second measure, which consolidates information sources, for example, work, capital, and energy, to bring down creation costs (Alola and Bekun 2020; Agboola et al., 2021; Gyamfi et al., 2021). It is considered wasteful when countries produce results without reducing the number of data sources used or by using an obsolete instrument that prevents a decrease in contributions to the base. In such a state, energy contributions to different sources of information are viewed as wastefully utilized and the energy squandered is noted. Methodologically, this can be evaluated as the extent of the planned energy contribution to the watched energy inputs. It has been impressively used to benchmark energy execution in various examinations (Liu et al., 2010; Valadkhani et al., 2016; Suzuki and Nijkamp 2016; Song et al., 2018).

METHODOLOGY

In the start, Data Envelopment Analysis (DEA) Model (Farrell 1957) and (Charnes and Cooper 1984) has been used to clarify the

TABLE 3 | Regional efficiency score.

Region	Efficiency
South Asia	0.25
ASEAN	0.34
Middle East	0.43
East Asia	0.71
Europe	0.25

set objectives of this study. The radial model is used here with the RTS variables. The structure of the said model is based on the mathematical input. In this model, the score of efficient energy θ is to be measured with kth DMU which stands for decision-making unit whereas kth is used for co-response of DMU for organizational business.

$$\text{Min}.\left\{\begin{array}{l}\theta|\theta X_k - \sum_{j=1}^{n}\lambda_j X_j - d^x = 0, \sum_{j=1}^{n}\lambda_j Y_j - d^y = Y_k, \\ \sum_{j=1}^{n}\lambda_j = 1 \geq 0\ (j = 1,...,n), d^x \geq 0, \quad d^y \geq 0,\ \theta: \text{URS}\end{array}\right\} \tag{1}$$

In this set where $X_j = (x_{1j}, x_{2j}, \ldots, x_{mj})^T > 0$ and $Y_j = (y_{1j}, y_{2j}, \ldots, Y_{sj})^T > 0$ the notation of T is representing the transpose of the vector, whereas d^x and d^y are representing the vectors in two columns which are used to represent the slacks of inputs and outputs. To represent the input columns vector of the decision-making unit up to the jth item. The following set has been used $X_j = (x_{1j}, x_{2j}, \ldots, x_{mj})^T$ which is supposed to be not less than zero on the same pattern for output column vector Yj should not be less than zero as under $Y_j = (y_{1j}, y_{2j}, \ldots Y_{sj})^T$. The notations of i is an indication of the input units up to i as $i = 1, \ldots, m$ Where as r is indicating the output units up to r as r = 1,. . .,s. The notation of j is used to represent decision-making units up to j as j = 1 . . . n. The total specified units of the decision-making model are examined up to kth units which have been elaborated here with k. In the range of data space of scalar λ_j is used to be a structural variable to analyze the relationship of units of decision making with one another. There are no restrictions on the score (Q) of energy efficiency in model (1). In both of the vectors as input (d^x) and for output (d^y) in their all components possess zero as a necessary condition for decision-making units efficiency. The dual dimensions of this model have been described as Max,

$$\{WY_k + \sigma | VX_k = 1, -Vk_j + WY_j + \sigma \leq 0\,(j = 1,...,n), V \geq 0, W \geq 0\}.$$

Here, V = (v_1,. . ., v_m) and W = (w_1,. . ., w_s) is two-row vectors of dual variables (multipliers) related to the first and second sets of constraints in Model (1). A dual variable (σ_i) is derived from the third constraint of Model (1) (Sueyoshi and Goto 2017). SCSC (Strong Complementary Slackness Condition): The Following Complementary Slackness Condition (CSC) exists between every optimal solution ($\theta^*, \lambda^*, d^{x*}, d^{y*}$) of Model (1) and every optimal solution (V^*, W^*, σ^*) of Model (2):

$$\begin{aligned}\lambda_j^*\left(-V^*X_j + W^*Y_j + \sigma^*\right) &= 0\,(j = 1, \ldots, n), \\ v_i^* d_i^* &= 0\,(j = 1, \ldots, m) \text{ and} \\ w_i^* d_r^{y*} &= 0\,(r = 1, \ldots, s).\end{aligned} \tag{2}$$

A pair of an optimal solution ($\theta^*, \lambda^*, d^{x*}, d^{y*}$) of **(1)** and an optimal solution (V^*, W^*, σ^*) of **(2)** satisfies the following conditions:

$$\lambda_j^* + V^*X_j - W^*Y_j - \sigma^* > 0\,(j = 1,...,m)$$
$$\text{and } w_i^* + d_r^{y*} > 0,\ (r = 1,...,s)$$

To deal with an occurrence of multiple projections and reference sets, we propose the following DEA model that combines Models (1) and (2) along with SCSC (Chen et al., 2016),

$$\text{Max.}\{n\,|\,\textit{All the contraints}\ (1)\ \textit{and}\ (2),\ \theta = WY_k + \sigma,\ \sigma: \text{URS}$$
$$\lambda + V\mathbf{X} - W\mathbf{Y} - \sigma e^T \geq \eta e^T,\ V^T + d^x \geq \eta e^T, W^T + d^y + \geq \eta e^T, \geq 0\}, \tag{3}$$

Charnes et al. the operation scientist favored DEA to measure the multidimensional relationship between energy

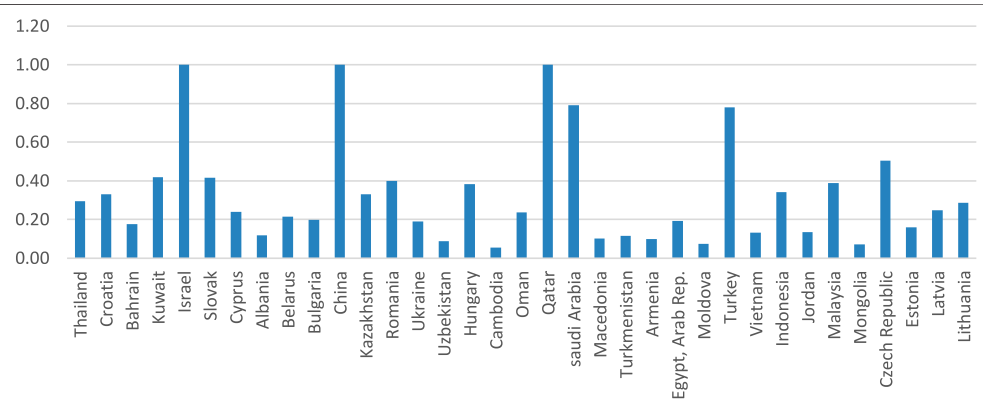

FIGURE 3 | Sensitivity analysis.

efficiency its demand under the various constraints. The objective of measurement of effective efficiency among provinces of the twenty-four countries is achieved through this paper by applying the DEA model. This model is used to evaluate the inputs and outputs of the same nature for DMU. The technology of mathematic programming is used as a piece of intellectual linear best practice to evaluate the defined efficiency of DMU establishing with the data of input samples. In each of twenty-four countries, x j is denoting the input vector of DMUJ in production decision making unit Yj denotes good output vector where b j denotes the bad output vector of DMUj (Zhou et al., 2007). Inputs of DMUs are representing capital, labor, and energy as good units of output in the total share of GDP whereas CO2 as its emission for all provinces is taken as the bad units of output. This model of DEA does not require additional information for being the already established mature measurement technique for the performance level of energy. This study is focusing on both models to measure the performance level of utilized energy along with its environmental effects. This methodology describes that the *k*th MMU if considered to be inefficient will be put on the frontier of efficiency by having projected these units. X_k^*, Y_k^* are the units which do not require such projections because these units are already reflecting the highest performance level. The following equation is representing the mathematical notation of putting *K*th item on the frontier of efficiency of DMU.

$$-\sum_{i=1}^{m} v_i X_{ik}^* + \sum_{r=1}^{s} w_r Y_{rk}^* + \sigma = 0$$

If we assume that *k*th DMU is on the efficiency frontier then this equation will be reshaped as

$$\sum_{j\in R_k} \lambda_j = 1 - \sum_{i=1}^{m} v_i \left(\sum_{j\in R_k} x_{ii} \lambda_j^* \right) \sum_{r=1}^{s} w_r \left(\sum_{j\in R_k} Y_{rj} \lambda_j^* \right) + \sigma \left(\sum_{j\in R_k} \lambda_j^* \right) = 0$$

or

$$\sum_{j\in R_k} \left(-\sum_{i=1}^{m} v_i x_{ii} + \sum_{r=1}^{s} W_r y_{rj} + \sigma \right) \lambda_j^* = 0. \quad (4)$$

Since the *j*th DMU $(j \in R_k)$ has $\lambda_j^* > 0$, *J*th is greater than zero and j belongs to R_k applying that *J*th DMU, we consider that all values of parameters as well as values of intercept are assessed by $-\sum_{i=1}^{m} v_i x_{ii} + \sum_{r=1}^{s} W_r y_{rj} + \sigma$ $(j \in R_k)$.

In the case of a multiplicity of output and input units in a data space, the hyper plan is the main characteristic of the framework of DEA. This indicator provides a reference set for the *k*th unit of decision-making for its characteristic of supporting hyperplane. This indicator also allows changing the location of this hyper-plane of discrimination if we want to distinguish the inefficient units from the efficient ones. For that purpose, we have used the change in the location of the hyperplane in the model of DEA. Although this model is found to be significant in this research, the level of applying this model to reduce the inefficient units is very high. We overcome this difficulty level by adopting these steps.

Step 1: we used an optimal solution of model (9) we divide the units of decision making into two sets as (E) for efficient and (IE) for inefficient (Zhou et al., 2006).

In Step 2: We have applied the below-mentioned type of the model DEA-DA upon both of the groups of efficient as well as inefficient groups Min. M $\sum_{j\in E} Z_j + \sum_{j\in IE} Z_j$

This model is used under the following condition

$$-\sum_{i=1}^{m} v_i x_{ii} + \sum_{r=1}^{s} W_r y_{rj} + \sigma + M z_j \geq 0,\ j \in E,$$

$$-\sum_{i=1}^{m} v_i x_{ii} + \sum_{r=1}^{s} W_r y_{rj} + \sigma - M z_j \leq -\varepsilon,\ j \in IE,$$

$$-\sum_{i=1}^{m} v_i + \sum_{r=1}^{s} W_r = 1,\ v_i \geq \varepsilon\zeta_{i,}\ i = 1, \ldots, m,\ w_r \geq \varepsilon\ r = 1, \ldots, s,$$

$$-\sum_{i=1}^{m} \zeta_{i,} = m,\ \sum_{r=1}^{s} \zeta_r = s,\ \sigma: \text{URS},\ v_i \geq 0 \text{ for all i},\ w_r \geq 0 \text{ for all r},$$

zj: binary for all j, ζi, : binary for all i, and ζi, : binary for all r. (6)

In the above notations, M is used to represent the large number whereas ε is to represent the small number. The two numbers need specification before going towards the solution of model 6. Zj is used here to clarify the incorrect units of decision-making counted by the Binary System out of the total number of objective functions (Lau 2013). While classifying and minimizing incorrect numbers of DMUs, the E (efficient member's group) are taken significantly at earlier than IE (inefficient member's group). For that purpose, we have added M to the E group of the model. The notations $-\sigma$ $(j \in E)$ and $-\sigma - \varepsilon$ $(j \in IE)$ are used to show the score of discrimination (Liu et al., 2015). The observations, existing in the function of discrimination estimation, are avoided through the small number ε. The classification of all DMUs is done through the following discrimination function $(-\sum_{i=1}^{m} v_i x_{ii} + \sum_{r=1}^{s} W_r y_{rj} + \sigma)$. The slope of the function in discrimination estimation is represented by the unknown weights of Vi and Wr is used for I = 1, ... n, and Wr is used for R = 1, ... s.

Both variables i.e. Vi and Wr are dual multipliers in Data Envelopment Analysis Model. The same variables are used in DEA-DA as unknown weights. The function used in the estimation of discrimination is representing the positive weights which are shown in the following constraints of the model

$$\left. \sum_{i=1}^{m} v_i + \sum_{r=1}^{s} w_r = 1,\ v_i \geq \varepsilon\zeta_{i,} i = 1, \ldots, m,\ w_r \geq \varepsilon\zeta_{r,} r = 1, \ldots, s \right) \quad (7)$$

Unity encompasses all the unknown weights that means the sum of all values of Vi and Wr are equal to one. This constraint confirms the normalization of the data. The counting of positive numbers of unknown weights is done through binary variables of the model where $(\zeta_{i,})$ represents counting of all variables of I and $(\zeta_{r,})$ represents an accounting of all the variables of r (Bampatsou and Halkos 2019; Broniszewski and Werle 2020; Pan et al., 2020). The lesser numbers then are controlled with their weights by applying the to the said binary variables keeping

in view the degree of freedom among the observed numbers of units of decision making (DMUs) along with the weights of the said three.

Step 3: This allows us to have an optimal solution when we are applying model 15 to the set of data. It also allows us the computation of the *J*th item/unit's score as following.

DMU:

$$\rho_j = -\sum_{i=1}^{m} v_i^* x_{ij} + \sum_{r=1}^{s} w_r^* y_{rj} + \overset{*}{\sigma} \text{ for all } j = 1, \ldots, n. \quad (8)$$

Step 4: is the process of computing scores of efficiency which are adjusted with the scores of PJ. Step four takes the following process a maximum.

(a) Ma x_j ρj is used to find the maximum values of efficiency scores whereas mi $n_j\rho_j$ is used to find the minimum values of efficiency adjusted score
(b) We define the range of the maximum and minimum values as in the case of positive values of maximum values of PJ we use
(b-1) range (A) = ma x_j ρj − mi $n_j\rho_j$ if ma x_j ρj is non-negative and
(b-2) range (B) = ma x_j $+\rho_j|\min_j\rho_j|$ if mi $n_j\rho_j$ is negative.
(c) The adjusted efficiency score for the *j*th DMU is measured by
(c-1) Efficiency = $[\rho_j - \min_j\rho_j]$ / [range(A)] if $\min_j\rho_j$ is non-negative and
(c-2) Efficiency = $[\rho_j + |\min_j\rho_j|]$/ [range(B)] if $\min_j\rho_j$ is negative.

Model (9) is used to find information for an efficient group of decision-making units and an inefficient group of DMUs. A model (15) is used here to separate both of the groups of DMUs by applying the functions of discrimination estimation. An adjusted score of efficiency for the *J*th item of DMU (j = 1, . . . n) replicates the estimated discrimination function. As a society, we have a great challenge of mitigating external climate change along with the reduction of emissions of (anthropogenic) CO2 and a reduction in the demand for energy. In all of the countries and all of the regions of the world, industrial operations are found to be the main source of CO2 emissions (Mach et al., 2016). Firms need to manage their functions of producing and increasing economic outputs in such a way that may ensure the reduction of CO2 emissions along with the reduction in the consumption of fossil fuels. The salient indicators of corporate social responsibility are said to be environmental and economic performance, which reflect the growth of society, indicating the sustainable development of society (Kjaerheim, 2005). Economic performance level is used by policymakers as a metric to manage economic efficiency and corporate culture or corporate environment (Hindiyeh et al., 2018). the ratio between the production level and the impact of the socio-economic environment can be improved and measured through this efficiency (Bjørn and Hauschild, 2013). The ratio of production level to the level of emissions of CO2 and consumption of energy must be taken by firms as a sustainable metric of economic performance level to mitigate the externalities of climate change as being the most preferred social duty of the corporate sector.

RESULTS AND DISCUSSION

Table 1 presents the descriptive statistics of the study. While comparing countries involved in this study with other countries, the enhancement in the performance level of clean energy and its cost must be fulfilled by thecorporations. The same need has been shown through the results of the Data Envelopment Analysis (DEA) model by its application to different sectors of society. The low value of the mean shows the low level of performance of least developed countries (LDCs) in which a reduction in carbon dioxide emissions and a reduction in energy consumption are needed along with the high-performance level of the economy. The performance level of cost in the context of the firm's distribution replicates the above notion. The quantitative survey demonstrates the importance of environmental policymakers and managers who can create a corporate culture in which low-efficiency producers can be persuaded to adopt a policy of lowering carbon dioxide emissions and energy consumption.

In **Table 2**, the score of measurement of efficiency lies between zero and one, which means that China and Russia bear this score of one (1), which shows the highest level of efficiency in clean energy. Saudi Arabia (0.93) comes in second, Singapore (0.90) comes in third, and Turkey (0.84) comes in fourth. In the same way, Israel is on the fifth number with a score of (0.82). In sixth place, Qatar (0.67), Poland (0.57) is seventh and Hungary (0.39) is eighth, whereas Romania (0.37) ranks ninth. Bangladesh (0.19), Uzbekistan (0.09), Mongolia, Cambodia (06), and the Kyrgzistan (0.04) are at the lowest level of performance for clean energy.

The results and estimations of the study for the selected countries are very similar to those of the countries studied by Zhou et al. (2012). The countries like Mongolia, Bangladesh, Kyrgzistan, and Cambodia, with respective scores of 0.06, 0.19, 0.04, and 0.06, are found to have the lowest performance levels among all the estimations. Stern (2012) found the lower values of estimations for three countries: Zimbabwe, Tanzania, and Ghana. The function of evaluation at a low-performance level will remain in operation for inefficient countries until and unless the public sector of these countries does not adopt efficient policies by inducting good management oriented towards environmental science. Through such short-term policies, a corporate culture of clean energy with reduced emissions of CO2 can be maintained in the countries that need it most in the energy sector. The same presentation of results has been presented below in **Figure 1**.

Developed countries and the least developed countries (LDCs) alike require a reduction in energy consumption along with a reduction in cost and a reduction in GHG emissions. A reduced level of all three can be achieved only with the higher level of energy performance. The International Energy Agency has in 2017 revealed this fact through its series of reports on the market that a 12% high level of energy could be consumed within the previous 17 years if the world achieved clean energy and cut waste in the energy sector. An amount of US $ 2.2 trillion was saved in 2016 with a downward trend of the intensity of energy around the world due to the enhanced level of performance of the energy sector. As a particular matter (PM), the sources of emissions at

the local level, which are carbon dioxide, nitrogen dioxide, and SOx, have been estimated along with the greenhouse gas externalities. Germany was proved to be the best example of saving local emissions of pollutants in 2014 as compared to that of the year 2000, which successfully avoided the emission of carbon dioxide with a score of 635 kT, which may be written as 7.7 kg/cap. Germany remained successful in avoiding 280 kt of nitrogen, which may be rewritten as 3.4 kg/cap of NOx. It avoided 82 kt of sox (1.0 kg/cap). It improved in particular matters with a score of 51 (0.52 kg/cap) and 23 kt (0.24 kg/cab). Due to energy efficiency, NOx was avoided up to 12%, SOx up to 13%, and particulate matter (PM10) was avoided up to 18%, whereas particulate matter (PM2.5) was avoided up to 14%, as per the comparison made by EEA in 2019, taking into account the total amount of other emission types in 2000.

The same goal of achieving energy efficiency in terms of total factors is to be the main objective of this study, in which DEA is applied for cross-sectional data. (Ouyang and Yang, 2020; Geng et al., 2019). While applying DEA to find out the enhanced level of performance in the total factor framework, we have to face unsuitable results in the shape of the score limit exceeding the given range. This problem is tackled in this study by applying the DEA model to 49 member countries so that this approach may become workable. We have successfully computed the scores of total factory EE with the application of the DEA model. We discovered that the United Kingdom, Israel, Singapore, Hungary, Qatar, and the United Arab Emirates are performing at a higher level in the energy sector, serving as a model for other countries (Sun et al., 2020a). The six countries mentioned above remained successful in achieving the goals of EE, whereas the other countries did not put this goal at the top of their priority list because of the reasons they failed to achieve this objective. Improvements in technology are recognized as a need by all EU member countries to increase efficiency in the energy sector. The European "Strategic Energy Technology Plan" is the crucial involvement in climate change and environmental improvements with the intervention of innovations through research and development in the field of technologies for energy. Technology is a sphere through which our objective of clean energy can be achieved. This is the main area in which all potential is to be utilized because there is a direct relationship between the enhancement of technology and the enhanced performance level of energy, which will result in a reduction in CO2 emissions and a reduction in consumption level consequently. The UK and Hungary are the countries that can be observed as role models. The policies of these countries in the energy sector deserve to be presented as the best policies to achieve sustainable and reliable development in mitigation of the externalities of climate change.

In 2015, Germany witnessed energy efficiency (EE) with the results of almost 2.2 (TD) and 1.1 (BU), a lower percentage of overall household expenditures. In the same year of 2015, the middle and low-income classes experienced more benefits, with the percentage of their overall household income corresponding to the scores of energy efficiency being 3.6 (TD) and 1.8 (BU). The level of heat generation and electricity production reflected harmful effects on the health and economic wellbeing of the public at the local level (Sun et al., 2020b). By improving the performance level of energy, we avoid the use of direct fossil fuel through such avoidance, we can save energy which will have a positive impact on the public health and economic condition. Thirty-one thousand cases of expected death were avoided through energy savings based on top-down mechanisms. On the other hand, based on the bottom-up savings, in the case of a particular matter (PM2.5), eighteen thousand emissions were avoided when this number was thirteen thousand for NOx. Based on the bottom-up approach, the savings were 12,800 for a particular matter (PM2.5) and this number was 9500 for NOx (Mohsin et al., 2019).

The General Regulations of the Electricity Regulatory Institute published a report on 11 April 2018 named "China Energy Development Report, 2017." A 2.9% increase has been shown in energy consumption as compared to its use in 2016. In 2016, the growth rate of energy consumption was 1.4%, whereas, in 2017, it remained at 1.5%, with an overall consumption of energy of 4.49 billion tonnes from coal. Considering 2016 as a base year for energy consumption, coal held a 60.4% share of the total production of energy, whereas clean energy comprised 20.8% of the total energy in 2017. The consumption of the source of coal was reduced by 1.6%, whereas an increase of 1.3% was observed in the consumption of clean energy (Peng et al., 2018).

Regional Energy Efficiency

The aggregate formation level of energy may be result-oriented to increase efficiency in the energy sector. This aggregate level is said to be the potential core in the case of the European Union when the UK leaves this union on 31 January 2020, which means the transitional period will last until 31 December 2020. This development has reshaped the whole scenario of research, including the past research results because the UK had been in a leading position among all other EU countries, so bearing the significant results other than the observations of this country, the data set cannot be thought of as complete, and dropping the value of this observation means a challenge to all past analyses made on the understudied subject matter. The change in the data set brings a change in the empirical results, so the TFEE approach has been employed in this study to compute the desired results by using the DEA model. This approach has the ability to estimate the higher performance level of disaggregated performance level for all data sets of future externalities of carbon dioxide emissions, gasoline consumption, and electricity consumption. The TFEE approach compares the disaggregate performance level of the UK as an EU member country with that of a level when it was not a member of the EU.

The regional performance level of energy has been clarified through **Table 3** and **Figure 2**. This table and the figure show that East Asia is at the highest level of regional efficiency with a score of 0.71 whereas South Asia is at the lowest score of 0.25 (Belaïd et al., 2018). Such a study may result in a significantly practical model for policymakers. This study is focusing on the

requirement conceptualization of the relationship between demand evolved due to enhancement in energy efficiency and price of this induced demand.

$$\text{Qd}\left(\text{Induced with efficiency}\right) = \text{f}\left(\text{P of energy}\right)$$

Such conceptualization of the theory of demand in the energy sector may be highly beneficial for industrial policymakers while defining implications of the expected requirement of coordination. The Other regions like ASEAN, Middle East, East Asia, Estonia, and Europe are bearing scores of 0.34, 0.43, 0.12, and 0.25 respectively. Germany does not show its better position in BBSR being a G7 country. A comprehensive research gap exists in this sphere of the low-performance level of energy in Germany. There is wide scope for a research study to find out the reasons due to which Germany is showing such results. The country has to be dependent on inputs in the energy sector, 60% of GDP of consumption of energy depends upon imports in 2015. The following are some reasons which do not allow the country to achieve the high-performance level in this sector:

1) Germany's energy market is not Pareto efficient, and it is not in a state of perfect competition.
2) Germany has to follow the European Union policy for its energy sector.
3) Germany has failed to reduce its reliance on fossil fuel energy.

This study provides a basis for policymaking for the sustainable development of clean energy for Germany, Denmark, and Sweden. The research studies of environmental science have declared that all policymakers and managers have recommended a reduction in energy consumption, a reduction in imported sources, and an enhancement in renewable sources of energy to achieve the target of the high-performance level on a priority basis. These policy options are the first basic necessary conditions for all entrepreneurs as well as for countries at the macro-level. Perfect competition in this sector can be ensured by the liberalization of its market in the energy sector. This scheme will provide a mechanism to divide the concentration in the retail market through the open entry of energy producers. In this way, a monopolistic system cannot influence the prices because low prices may increase the consumption level of energy, which is not desirable. To avoid such a situation and to ensure the effective level of energy consumption, the governments of Slovenia and Poland have imposed taxes because the low consumption of energy is also an indicator of a high-performance level of energy.

Discussion

Throughout the world, energy efficiency (EE) is the key feature of all local and national government policy strategies. According to the OECD/IEA report, this salient feature is characterized by a high level of savings through cost-cutting techniques, keeping the objective of climate change mitigation on target. As compared to 2016, an amount of US $236 billion has been invested, with an increase of 3% in 2017. In 1970, the world experienced an oil crisis, during which most countries focused on energy efficiency and went through the scientific literature on the topic.

Since 1970, the energy policy had been set at top priority in all of the countries with time; focus had been shifted to greenhouse gas to bring the negative effects to minimum levels. The area of research has been expanded up to technical engineering and up to the fields of behavioral and organizational economics through which the practical implementation strategies are coming to be adopted. In 2017, the emission of CO2 increased up to 1.4% around the world even though practical and scientific policies and strategies have been adopted by all economies over the last 40 years. The highest emission score is 32.5 Giga tones after having experienced the flat emission rate for 3 years at the global level.

The objective of achieving a clean energy environment is not so easy, despite the focus of governments and worldwide policies to make it possible. The current techno-economic framework is characterized by modern social economists as inconvenient in terms of creating an environment that may ensure a solution-finding system. Disentangling energy efficiency is critically crucial for orientations of performance enhancement and practical economic implementation in the context of the socio-economic environment. The need for energy efficiency is an aspect of our society that is rich in innovative movements on technical ground. So there is a scope for conceptualization and innovation in introducing the new set pattern on both sides, as on-demand as well as on the production side. This is the sector that is deemed the top agenda item of the European Union's 2030 climate and energy policy objectives. The same object has been focused on by IEEE (International Energy Agency). The Energy Union has been established to achieve the following five objectives:

1) energy consumption methods that are sustainable, dependable, and secure
2) a critical examination of the energy sector's internal market
3) a perfect economy free of carbon dioxide emissions
4) creating a research environment by establishing novel conceptualization methods.

Even in the modern world, we do not have such options on the practical ground through which the target of enhanced performance level and reduced cost may be adopted at the same time. More and more focus has been concentrated on saving energy. As has been clarified by many research studies, saving of energy should be coupled with cost-efficiency. This approach of coupling benefits, as higher performance level plus higher competition level, along with the fruitful results of health and other economic sectors, is more beneficial than adopting policies of cost-cutting. Any cost-cutting policies should also be coupled with the other benefits of energy efficiency (EE) policies. Normally, equipment is not considered while considering externalities like extra demand for energy in the course of achieving energy efficiency, which is only because of the absence of consideration of upstream change. Some other important indicators, like reductions in revenues due to a reduction in tax implementation and enhanced levels of

unemployment, remain unconsidered during our study's methodological framework.

Since the 1970s, Denmark has been dependent on imported sources of energy, but is now going to be dependent on its local resources for the production of energy. This country is exporting fuel as well as electricity now. This country has achieved this objective by adopting the following policy measures:

- Being Fluency
- Controlling the emission of carbon dioxide and of electricity
- Technology is considered a factor of production in the present economic theory.

Denmark has adopted the new technology of energy production through wind turbines and thermal power. Sweden is fully dependent on the EU energy market, even though the EU is trying to shut down the nuclear plants in Sweden. The EU energy market is enjoying high energy prices in its exports due to the fact that its hydropower development is on an increasing trend, through which exports are also increasing at increasing rates. In the case of lower energy prices, imports get developed and hydropower development is stopped. Sweden will have to wait to adopt the policies for system development for sustainable price mechanisms. To fulfill the energy requirements, Luxembourg depended on imported sources of electricity and fossil fuels. It experienced a low value-added fuel tax because its government has been focusing on energy security. The country has set up a national renewable energy action plan for 2020 to achieve the desired level of energy through achieving energy efficiency by adopting an innovative technological framework. In Luxembourg, the share of energy consumption is 11% of the share of RES, heat consumption has an 8.5% share of RES, 12% is the share of the demand for electricity and 10% is the share of overall energy demand to RES (EU commission, 2009–2016). The government of the United Kingdom has a policy of high prices in the energy sector so that the investment in the energy sector can be enhanced to give rise to a way of producing energy without the emission or utilization of carbon. It is because the government is about to enter the new phase of the energy environment with new technologies of production in this sector. We have summarised here the policy measures of four EU member countries, which are Denmark, Sweden, Luxembourg, and the UK. The salient features of the collective policy options of these four countries are as below:

- The imposition of taxation to raise the price
- Control over the transactions of the electricity market
- Sustainable price policies
- Setting up goals to achieve the desired level of sustainable and clean energy

The energy efficiency of each country can be controlled by inducing an effective approach to estimation. Comparison of the policies of different countries may help to monitor their energy efficiency levels separately. Investigation of current and future systems of energy-producing organizations may provide the basis of a monitoring mechanism for countries at the individual level. This study is a judgment of the viability of the implementation of total factor energy efficiency within the framework of the DEA model.

Sensitivity Analysis

When we apply the research gap CSW to the international Malmquist Productivity Index (Kao, 2010), the homogenous observations of general weights are taken in the set of units of inputs and outputs for the whole time-series data. The sensitivity analysis results are presented in **Figure 3**.

Policymakers estimate all units of the decision-making process as per their specific characteristics to manage the variations over time. It is due to the change in regulations introduced by the government in the energy and waste management sectors. To find out the different results of different ranks of units of decision making (DMU), we apply the linear programming model of the ideal point method, which provides us with multiple optimal solutions for feasible equilibrium. To establish CSW in the context of the Malmquist Productivity Index, we use a quadratic form of the Ideal Point Method through which we can avoid the problem of multiple solutions and find a unique optimal solution.

CONCLUSION AND POLICY IMPLICATION

The analysis of energy efficiency has become pretty interesting due to the awareness campaign describing the problems of the sector. All the previous studies made in this area of efficient environmental design have discussed the ways of controlling the negative externalities. DEA has provided an optimal combination of effective energy among 35 decision-making units. It provides a sound basis for bringing the possible highest level of performance from energy through a reduction in negative externalities like emissions while leaving economic growth unchanged. The conventional use of the DEA model shows rebound problems that have been replaced in this study by introducing some alternative ways to overcome the undesirable results associated with this model. The project approach, which is used to adopt a replacement approach to different performance levels evaluated in business and social economics, has future applications. The score of the measurement of efficiency lies between zero and one, which means that China and Russia bear this score of one (1), which shows the highest level of efficiency in clean energy. Saudi Arabia (0.93) comes in second, Singapore (0.90) comes in third, and Turkey (0.84) comes in fourth. In the same way, Israel is on the fifth number with a score of (0.82). On the sixth number in Qatar (0.67), Poland (0.57) is on the seventh and Hungary (0.39) is on the eighth, whereas Romania (0.37) is on the ninth number. Bangladesh (0.19), Uzbekistan (0.09), Mongolia, Cambodia (0.05), and Kyrgyzstan (0.04) are at the lowest level of performance for clean energy.

The emission level of greenhouse gases (GHGs) in developed countries is found to be better in the context of improvement in performance enhancement in the sector of the energy mix. The

score of evasion is measured as 365 kt of CO2. This score for NO2 is 280 kt and for SO2 is 82 kt, whereas it is 23 kt (0.24 kg/cap) of particulate hazardous matter. The higher performance level of energy yields a negative relationship with emissions of gases, with a significant number of 12% for NO2 in 2000, as compared to 13% for SO2 and 14% for PM2.5. Whereas PM10 has the highest concentration (18%). Public policymakers may enhance the facilitation system for better free trade and a result-oriented corporate environment to enhance the performance level of energy in the electricity sector. The value of the component of efficiency change is less than unity, which means it has a negative relationship with a higher level of energy performance. Different large provinces are found to be inconsistent within different sectors of the industry, so these do not remain able to perform at their best level. Equal weights have been used to calculate the EPIS in this study. The economic value of energy efficiency has been influenced by different weights. This dynamic effect of different weight settings may be examined in some of our future studies if the data is available. We would be applying the presently used methodology to estimate the low level of performance in industrial sectors. Through the application of this model, we will be able to have a deep insight into establishing the basis for a society that possesses environmentally friendly characteristics.

Policy Implication

1) The adoption of advanced technological design and the maintenance of the minimization of purchase and production waste can help to achieve high-performance levels of environmental indicators and, more broadly, the improvement of sustainable development scales. Due to the higher level of demand and consumption of energy, we have to compromise on an undesirable air quality index. Sustainable development and a higher level of environmental performance may be improved through the use of innovative technological designs, keeping in view the upcoming modern trends in environmental sciences.
2) Because efficient energy techniques and economic innovative approaches have contributed to sustainable development and green transformation, policymakers must make decisions based on weighing energy and environmental performance indicators in the process of assessing modern technology procedures. The specified positive relationship between energy consumption and greenhouse emissions demands a high level of priority given by policymakers to the input variables such as consumption as compared to the negative externalities of output variables such as emissions of GHG. This relationship becomes more effective in the case of industries whose energy intensity is higher because high-intensive industries are found to be less efficient in the energy sector. The higher good-quality index can be achieved along with cost efficiency by adopting the input variable techniques through which we can experience high potential in achieving our desired goals of energy efficiency and reduction of energy consumption.
3) If the public sector is interested in achieving the improved energy environment and corporate culture of an innovative technological socio-economic environment, then investment should be channeled into research and development (R&D) as innovation has become a crucial part of environmental efficiency, which has a rebound capacity for economic development as a matter of the investment made in this sector. Energy efficiency plays a distinguished role in the enhanced level of clean energy and the reduced level of GHG emissions. The specific characteristics of weaknesses and strengths of different economies should be kept in mind by policymakers while formulating the framework of policies and strategies.
4) The Energy Union has set a high-performance level of energy as its top priority agenda, with reductions in greenhouse gases and dependence on imported resources, reductions in unemployment, reductions in energy insecurity, enhancements in R&D and innovative technological technologies, and enhancements in competition level all possible through improved energy performance. The construction sector in Europe is the top-ranked end-user, consuming 40% of primary energy and 36% of greenhouse emissions.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Does Economic Development Impact CO_2 Emissions and Energy Efficiency Performance? Fresh Evidences From Europe

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Data from a survey of 21 European nations from 2006 to 2018 investigates the relationship between economic development and carbon dioxide emissions. The PCA of normalised factors is used to create three quantitative measures for financial intermediation dependent on the results of the study. When estimating the framework, we used the Hoechle method, which generates systematic deviation for linear panel styles that really are not homoskedasticity coherent and moreover resistant to broad types of cross-sectional dependency. We observe that earnings, resource utilization, industrialization, urbanisation, foreign direct investment, and the banking system all seem to have contributed to increased carbon dioxide emissions in the area. However, greater economic access appears to have resulted in a reduction in greenhouse gas emissions. In terms of quality, the results are resilient to a variety of alternative proxies for financial inclusions as well as acceptable changes to the conceptual framework. According to the empirical findings, there are currently no regulatory interactions linking increasing economic development and reducing carbon dioxide emissions at the national level. As a result, economic growth should be incorporated into the implementation of sustainable green economy plans at the municipal, provincial, and city levels, particularly to counteract the documented detrimental impact of higher carbon dioxide emissions associated with increased financial inclusion.

Keywords: carbon di oxide emissions, economic develeopment, green economy, Europe, Econometric analys1s

1. INTRODUCTION

The aspect of financial development is integral to that of the economy (Galindo et al., 2003). Increasing economic development is an important part of growing the banking system and establishing new organizations. Research that identified financial barriers as a significant driver of impoverishment spurred the development of the idea of financial intermediation in the early 1990s (Elliott et al., 2003). This means that all people and companies should have access to a wide range of investment vehicles, including exchanges, remittances, deposits, and credit facilities, in order to fulfil their requirements at a reasonable price in a sustainable and long-term way (Allayannis and Ofek 2001). Carbon dioxide emissions are a significant contributor to GHG emissions and the

development of severe weather events, both of which are frequently used as environmental factors due to their role as GHGs (Pantzalis et al., 2001; Makino et al., 2007; Cheema et al., 2020).

Greenhouse emissions and usage have risen in tandem as world production has expanded, pushing up emissions of carbon dioxide. As per the International Energy Agency, worldwide non-renewable resource emissions of carbon dioxide rose by 65% between 1980 and 2018 (Glaum et al., 2000). Besides uncontrolled elements, including seasonal changes and environmental catastrophes, human-produced emissions of carbon dioxide have had a significant effect on world total greenhouse gas emissions. The impact of climate change has been exacerbated significantly by human-caused carbon dioxide emissions. Therefore, it seems critical at this point to create a single market for selling exhaust emissions as well as good rules and regulations to control carbon dioxide emissions (Froot et al., 1993; Chen et al., 1997). It is indeed possible that economic development will have both constructive and undesirable consequences for emissions of carbon dioxide. Financial inclusion, on the one hand, makes it simpler for companies and people to do this, and cheap financial schemes make a significant contribution to renewable technology more realistic (Bodnar and Wong 2003; Kim et al., 2020). To put it another way, comprehensive banking systems have significant ecological effects by producing quality sustainability initiatives that are more accessible and affordable, and therefore reduce carbon dioxide emissions (Gilchrist and Zakrajšek 2012).

Promoting economic development is especially important for impoverished areas where producers do not have access to money or financing to engage in renewable technologies, including photovoltaic distributed generation, that would be both financially efficient and, moreover, generate a lot fewer carbon dioxide emissions compared to direct combustion. Money constraints (lack of state funding support and commercial lending options) have been identified as major barriers to the adoption of renewable household installations in Vietnam (Lustig et al., 2011). Such stories demonstrate how the supply of cheap economic commodities may help encourage the deployment of reducing emissions and the acceptance of ecologically friendly solutions that cut emissions of carbon dioxide by consuming fewer energy sources. The inverse connection exists among the domestic financial economies as well. There is a significant correlation between domestic and company profitability and the present period of the economic downturn, which may be seen in fundamental budgetary constraints, productivity, and the banking sector's structural rigidity. average annual increase and the asset values of debtors are enhanced while the business is in a period of rapid recession, improving the dependability of market mechanisms (Bruno and Shin 2017; Call et al., 2021). Receding economies, on the other hand, result in reduced earnings and dependability. Higher than the market value, money transmitters' extra costs and percentage earnings include some consistently growing ingredients. It can be deduced that the solvency position and checking account placement of the financial intermediation are intrinsically correlated to mortgage holder financial health and therefore react appropriately to investor sentiment that is volatile and affected by economic transitions between various stages of market cycles (McBrady and Schill 2007; Cook et al., 2008).

In the 1960s and 1970s, researchers started looking for a connection connecting ecological strategy and organisational financial planning. As a result, there are now primarily two research directions. Effectiveness and efficiency have been shown to have a beneficial impact, and this stream emphasises the significance of creating shared benefit for all stakeholders. According (Colin et al., 2008; Hoberg and Moon 2017), green marketing and CFP have a beneficial relationship, especially in the face of increasing cultural and practical constraints. As of late, green marketing and CFP have been affected by environmental entrepreneurship, according to a study by Sánchez-Medina et al. Considering ecological trends as part of the organisational context is essential for achieving synergy. According to numerous studies, environmental development and CFP go hand in hand (Altman 1968; Allayannis et al., 2001; Bharath and Tyler, 2008). It is true that environmentally friendly innovations like garbage management and improved system performance help to improve CFP while at the same time reducing expenses. According to the research (Cheng et al., 2020; Li et al., 2021).

Affordability promotes operations and economic pollution, which then in turn generates emissions of carbon dioxide, which in turn can enhance the threat of climate change (Cheng et al., 2019; Liu et al., 2021). Economic development also allows customers to purchase luxury products like cars, microwaves, and exhausts whose usage is environmentally hazardous due to the increased emission of GHGs (Ma et al., 2013; Wu and Zhao 2018; He, 2019). Accessible banking markets encourage financial development and, as a result, stimulate domestic use of damaging renewable resources, which increases greenhouse gas emissions (Lea, 2017; Jiang et al., 2019; Yang et al., 2020). It is difficult to control carbon dioxide emissions because of the variations in government legislation, geography, and a host of other variables, and the presence of different economic obstacles. Co2 emissions (CO2) are the most important major cause of global warming, accounting for 80% of all GHGs (Li et al., 2020; Zhu et al., 2020). These pollutants increased rapidly from 1980 to 2015, per person. Emissions of carbon dioxide rose from 4.0452 metric tonnes in 1980 to 5.7865 metric tonnes in 2015. Carbon dioxide emissions increased by 1.5 percent during this time period (Song and Shi 2018; Song et al., 2019). EU emissions in 1970 were 7.0896 metric tonnes per person, and they decreased to 5.6895 metric tonnes per person in 2017 as relative to the overall globe. Above, one of the sentient Greenhouse gases are attributable to fossil fuel-based power production, which is causing an increase in global warming as a result of carbon dioxide concentrations steadily rising (Luo et al., 2019; Heidari et al., 2019). As a result, the world faces grave repercussions, including the potential reversal of centuries of stability and prosperity. Without drastic measures to reduce contamination, the public believes the earth is doomed to ecological catastrophe (Luo et al., 2019).

According to the findings of this research, economic developement has a significant effect on climate change.

Several more research findings have shown the impact of economic developement on emissions of carbon dioxide (for example, in advanced economies (Wang and Xia, 2019), in Italy, in France, in Spain, in Germany, and in the United Kingdom). This research investigates Since economic developement and global warming are both important issues in Europe, the area was selected as the focus of our research project. The question, however, is whether providing adequate banking institutions to all people, especially those in the most disadvantaged sectors of society, helps to reduce greenhouse gas emissions in the area in particular.

The remainder of this research is structured as follows. **Section 2** explains the literature review. The baseline model, data, and methods are presented in **Section 3**. The empirical findings are discussed in **Section 4**. The research comes to a close in **Section 5**.

2. LITERATURE REVIEW

The means it provides in both the advanced and developing worlds may help to mitigate ecological damage by shifting away from carbon-intensive renewable resources and toward communications and related industries (Zhang et al., 2020). Energy efficiency has been greatly decreased in industrialised nations as a result of technical development, sustainable development, and strategies relating to the implementation of legislative requirements, all of which have contributed to a reduction in greenhouse gas emissions (Mategaonkar and Eldho 2012). Furthermore, in emerging economies, transportation, food security, industry, and the financial services industry are the primary sources of increased carbon dioxide emissions (Heidari et al., 2019). As a result, emerging nations serve as havens for fuel businesses and a heavy reliance on alternative sources of energy that cause environmental problems in the end (Sihwail et al., 2020). releasing environmentally harmful and temperature-polluting pollutants. The rationale for this is that many rising and developing nations, particularly the poorer ones, face an urgent desire to actually increase their economic development at any cost, including the degradation of ecological sustainability. Per capita emissions, on the other hand, tend to be high in industrialised nations, but the pace of emissions increases is indeed substantial in certain less advanced economies. They have also generated more than 75% of global carbon dioxide emissions, most frequently in 2018 (Yang et al., 2013). The goal was to address problems such as uncontrolled resources and environmental deterioration, including other concerns. A renewable energy industry, according to the UNEP, is "one which improves human well-being and economic justice while substantially decreasing risks to the environment and ecosystem resource shortages." A framework for new communications an understanding of the promotion of macroeconomic stability was established after the 2008 recession, which has led to the mainstreaming of the green economy into socioeconomic discussions (Majumder and Eldho 2020; Chen et al., 2020; Asad, Khan, and Krol 2021). The idea is referred to as a low economic structure, which seeks to reduce emissions of greenhouse gases while reducing energy usage and productivity (Huang and Mayer 1997; Philippe et al., 2021). the world's significant policy initiatives (Yang et al., 2013; Zhang et al., 2020). Notwithstanding all of these measures, carbon emissions continue to rise, and what is even more concerning is that studies suggest they have not even reached their high yet (Luo et al., 2014; Piscopo et al., 2015). Earlier research attempts have shown this to be difficult, and three possible explanations have been offered. When it comes to carbon-based energy supplies and greenhouse gas emissions, most research has focused on accumulated implications (coal and oil) rather than based on demographic effects like charcoal, gasoline, and other energy sources. Furthermore, research on the increases in energy has tended to emphasise the consequences of utilisation rather than processing. What a shock, given the data showing that economic growth is linked to energy resource generation as well as consumption, particularly during the introduction stage! (Seyedpour et al., 2019). Furthermore, assessing the adverse hazards of energy supplies solely from a consumer's perspective without considering development would almost certainly lead to a misunderstanding of management among researchers. Third, financial liberalisation should have a more uniform effect on global sustainability (i.e., a substitute for business as a percentage of gross domestic product) before taking the diverse effects into account (i.e., imports and exports) (Wang and Xie 2019; Scardapane et al., 2015). Ecological and sustainability concerns and possibilities are already being incorporated into financial organisations' business strategies. The Green Banking Network and the United Nations environmental Direct Involvement are two similar organisations. Diverse elements of sustainable and eco-friendly financing must be addressed in the global arena. Because of the corporate sector's participation in the battle against contamination, these initiatives succeed. Building a green economy relies heavily on foreign international banking institutions (Opitz et al., 2016). Leaders from all sectors, governmental and commercial, have begun to place a higher value on conservation in recent decades. And so now, banks are beginning to place a higher value on sustainability. Business executives are contemplating ways to move the world's trade towards more environmentally friendly practises while also recognising the firm's effect on society, particularly in light of recent technological advancements like artificial intelligence (AI) and robotics (Sirota et al., 2008).

We built an econometric technique of equilibrium was reached with various economic and social tensions sources when studying the equilibria impact of various budget restrictions and their effects on gross domestic product, total factor productivity, and economic development (Asher et al., 2015). There are two important ramifications to using our approach. To begin, policy tools should aim at even the most limiting restriction, which itself is likely to vary from country to country. By presuming that almost all nations have the same kind of restriction, we may be predicting the market's reaction in the wrong way (Gao et al., 2021). Loosening security requirements, for example, may increase employment in one country but not in another where economic developement is hampered by high lending rates. Finally, financial inclusion, gross domestic

product, and wage levels all have costs and benefits. Furthermore, short-term transitory impacts may vary from long-term set point results (Sitnikova et al., 2008; Mazaheri et al., 2018). That could take a decade. 1stWide income disparity may result from initiatives that boost gross domestic product, but the magnitude of imports and exports can fluctuate. We offer authorities with a comprehensive strategy so that they will be aware of the challenges they will encounter in the future and may plan accordingly, if necessary, or select another course of action if necessary.

3. DATA AND METHODOLOGY

According to the findings of this research, decreasing GHGs is an important part of the effort to halt global warming in Europe. Beginning with "STIRPAT" framework, we use the conceptual and methodological approach.

$$I_{it} = \alpha_{it} P_{it}^{\beta_1} A_{it}^{\beta_2} T_{it}^{\beta_3} \varepsilon_{it}. \tag{1}$$

Affluence (A) and technological advancement (T) have an impact on the environment, but population (P) and affluence are the two that have the most ecological footprint at any given moment. P, A, and T all have elasticity coefficients of 1–3, which correspond to the elasticity of environmental impacts (as measured by global greenhouse gas emissions). To logarithmically represent the data in framework 1, do the following:

$$lnI_{it} = \alpha_{it} + \beta_1 lnP_{it} + \beta_2 lnA_{it} + \beta_3 lnT_{it} + \varepsilon_{it} \tag{2}$$

Beyond financial services, this research expands on **Eq. 2** by looking at a variety of extra dependent variables, most of which have been recognised by the available research as having an impact on greenhouse gases, particularly regarding urbanisation (Lovell et al., 2012), structural transformation (Ye et al., 2021), real exchange rate (Terzano et al., 2001; Bollt 2021), and economic growth (Hening 2004; Parrino et al., 2006; Faes et al., 2012). According to the average approach in **Eq. 2**, this research calculates per capita costs by dividing the supply and demand variables by the larger community. All factors except financial development inclusion are expressed as logarithms. 1stAs a result, the preceding is the survey's foundational approach.

$$\begin{aligned} lnGHG_{i,t} = \beta_0 + \beta_1 \times lnINC_{i,t} + \beta_2 \times lnENE_{i,t} + \beta_3 \times FDI_{i,t} \\ + \beta_4 \times lnTRADE_{i,t} + \beta_5 \times lnURB_{i,t} + \beta_6 \\ \times lnFIN_{i,t} + \beta_7 \times lnIND_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{3}$$

Numerous financial formulations examine the link involving Emissions of carbon dioxide and Gross domestic product. In light of this, we went with a log-linear description to see how growth of the economy and other key factors affect emission of carbon dioxide. As a result, the log-linear mathematical expression is preferred over the generalised linear because aberrations are less important in influencing the calculated parameters. The preceding is the shape that our fundamental model presupposes:

$$\begin{aligned} lnCO2_{it} = \propto_i + \propto_1 lnCO2_{it-1} + \alpha_2 GDP_{it} + \propto_3 FIN_{it} + \propto_4 TR_{it} \\ + \propto_5 FDI_{it} + \propto_6 SCH_{it} + \propto_7 POP_{it} + \varepsilon_{it} \end{aligned} \tag{4}$$

$$CO2_{it} = f\,(CO2_{it-1}, GDP_{it}, FIN_{it}, TR_{it}, FDI_{it}, SCH_{it}, POP_{it}) \tag{5}$$

In addition, we approach prior research (Kato et al., 2003; Faes et al., 2012; Lobier et al., 2014) and incorporate the income square factor according to the above formula in order to determine the applicability of the Environmental Kuznets curve in the present research. The final model looks like this:

$$\begin{aligned} lnCO2_{it} = \beta_i + \beta_1 lnCO2_{it-1} + \beta_2 GDP_{it} + \beta_3 GDP_{it}^2 + \beta_4 FIN_{it} \\ + \beta_5 TR_{it} + \beta_6 FDI_{it} + \beta_7 SCH_{it} + \beta_8 POP_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

As a preliminary step, we assert that capital accumulation may be a determining element in the earnings relationship. The exponential relationship factor of bank profitability per disposable income is included in **Eq. 6** to represent this impact explanatory variable. As a consequence, we get the following equation:

$$\begin{aligned} lnCO2_{it} = \beta_i + \beta_1 lnCO2_{it-1} + \beta_2 GDP_{it} + \beta_2^* GDP_{it} * FIN_{it} \\ + \beta_3 FIN_{it} + \beta_4 TR_{it} + \beta_5 FDI_{it} + \beta_6 SCH_{it} + \beta_7 POP_{it} + \varepsilon_{it} \end{aligned} \tag{7}$$

In the research on ecological protection, financial development is considered to have an effect on global sustainability, primarily affecting key growth drivers including foreign direct investment (FDI) and the relationship between economic growth and the accompanying analysis method may be used to examine the moderating impact of trade liberalisation access on direct investment:

$$\begin{aligned} lnCO2_{it} = \beta_i + \beta_1 lnCO2_{it-1} + \beta_2 GDP_{it} + \beta_3 FIN_{it} \\ + \beta_4 TR_{it} + \beta_4^* FIN_{it} * TR_{it} + \beta_5 FDI_{it} \\ + \beta_6 SCH_{it} + \beta_7 POP_{it} + \varepsilon_{it} \end{aligned} \tag{8}$$

We also use the linear formulas to evaluate the mitigating impacts of foreign direct bank profitability, see (Ahmed et al., 2011):

$$\begin{aligned} lnCO2_{it} = \beta_i + \beta_1 lnCO2_{it-1} + \beta_2 GDP_{it} + \beta_3 FIN_{it} + \beta_4 TR_{it} + \beta_5 FDI_{it} \\ + \beta_5^* FIN_{it} * FDI_{it5} + \beta_6 SCH_{it} + \beta_7 POP_{it} + \varepsilon_{it} \end{aligned} \tag{9}$$

Financing is a significant intervention that may be required in this study. We create a Economic developement Indicator that takes five different facets of economic developement into account while constructing this statistic. The information comes from the Global Financial Performance Statistics of the World Economic Forum. Our sampling procedures span the years 2006–2018, according to information available. There are 21 nations in all. A list of descriptive analysis and inferential sources may be found in **Table 1**.

TABLE 1 | Variable's definition, data sources and statistical descriptions (21 countries) 2006–2018.

Variable	Description	Source	Obs	Mean	Std. Dev.	Min	Max
INC	GDP per capita (constant 2010 US$)	WDI	296	19650.84	21,209.62	421.983	81276.09
POPG	Population growth (annual%)	WDI	296	3.84650	3.87023	–0.19342	21.38422
URB	Urban population (% of total population)	WDI	296	61.20376	32.70942	21.40921	101.9837
ENE	Energy intensity level of primary energy (MJ/$2011 PPP GDP)	WDI	296	6.09231	4.710923	0.23982	21.78327
IND	Industry (including construction), value added (% of GDP)	WDI	267	39.30912	19.38730	4.78216	81.34213
TRADE	Trade (% of GDP)	WDI	289	111.3409	71.62091	19.7823	501.6734
FDI	Foreign direct investment, net inflows (% of GDP)	WDI	289	6.89342	8.88467	–5.78342	49.87212
CO2	CO2 emissions (metric tons per capita)	WDI	289	9.30921	9.59043	0.78543	68.87905
FI1	Automated Teller Machines (ATMs) per 100,000 adults	GFDD	254	51.37274	61.02358	2.78340	301.5478
FI2	Branches of commercial banks per 100,000 adults	GFDD	243	19.34298	8.67594	1.43294	59.78390
FI3	Institutions of commercial banks	GFDD	287	49.27142	39.5902	4.90211	302.4893
FI4	Outstanding deposits with commercial banks (% of GDP)	GFDD	267	59.32415	51.63097	4.78032	249.5537
FI5	Outstanding loans with commercial banks (% of GDP)	GFDD	221	39.43209	29.62894	2.689102	189.2356

TABLE 2 | Summary statistics.

Variable	Mean	Standard deviation	Minimum	Maximum
CO_2	0.710	2.673	–3.647	3.094
GDP	6.3987	1.323	3.563	9.654
POP	21.091	1.209	9.476	19.543
TD	5.3921	1.784	1.894	7.092
HC	2.6789	0.462	0.218	3.532
FDI	0.2212	1.302	–3.747	7.375
FSDGDP	4.6703	0.983	0.642	6.453
DCFS	4.6793	2.794	–2.867	6.382
DCPS	4.7822	0.675	–0.321	6.091
TDGDP	2.7932	0.609	–0.747	8.242
M3GDP	4.0931	0.78	2.674	6.209

4. RESULTS AND DISCUSSION

4.1 Estimation Analysis

Factors of economic growth are presented in a multitude of separate categories and measures in **Table.1**. Additionally, the variation of certain factors is large, whereas the variability of others is minimal. Although they may be combined to create a price measure, those signals must be transformed into normalised quantities (D. Li et al., 2010). The normalised parameters are then subjected to PCA. We use various normalising approaches, such as z-score, maximal, and non-linear activation procedures, to compare and evaluate the robustness of our economic development factor. As a result, we have several approximations for it.

Earlier, the Wooldridge (2002) test and the Revised Wald test were used to evaluate two distinct assertions about the regression model, namely with the test of normality. At the 1% range, the findings in **Table 3** show cointegration and collinearity. **Table 3** also shows cross-sectional dependency with a co integration definition, as the findings show.

The research evaluates the designs using the error correction framework suggested by (Salinas et al., 2014). (SCC). We used that programme because the (Griffis and Stedinger 2007) measurement deviations produced by (Neves et al., 2016) are both autoregressive conditional reliable and resistant to extremely broad types of multi and longitudinal relying concepts (Magnus and Vasnev 2015). This research used imbalanced boards, thus the xtscc software was able to function effectively using these too. It is capable of dealing with numbers that are not present (Noor et al., 2010). Lower overall for correlations using the pooled Generalized Least Dividers Method. For reference and thoroughness (Grantham and Ungar 1990), computed instrumental variables (inside) and consolidated regression multiple regression analysis are computed by (Shen et al., 2020) for reference and thoroughness. Banking supplies must be geared toward the requirements of corporates in an attempt to develop commercial potential and attain community fellowship in order to accommodate citizens into economic institutions. As a result, according to (Lundby et al., 2021), financial instruments like credit and savings lead to more high satisfaction and help everyone's macroeconomic circumstances throughout the globe. Constraints such as adverse selection, affordability, costs and benefits of the banking system, terrible financial literacy, distrust of the banking industry and peers must always be recognised and addressed in order to provide maximum progress in economic advancement (Hao et al., 2021; Cozad et al., 2015). Most research has not emphasised identifying strengths and limitations of increasing the potential for economic growth within the sector's significant development. Financial intermediary inclusion has been discussed, but the underlying causes of disparity and community cohesion in digital finance advancements have yet to be fully investigated (Chai et al., 2017; Scutari et al., 2019). Furthermore, other research has looked at the effect of European digital and mobile banking services.

There are many examples of how digital payments and m-banking (Sammaknejad et al., 2019) have created a business development phenomenon and how they want to penetrate the market, such as (Gao and Shardt 2021). Based on the state's strategy, a recent research (Mahjoub et al., 2012) concluded that the concept of inclusive growth is conspicuously absent from official digital initiatives and policies. Wealth management and the main types of communication in the rural environment have yet to be tested, so it is unclear as to whether they promote financial inclusion. We made sure to account for a wide range of variables that might influence financial inclusion. The logarithm

TABLE 3 | Results of diagnostic tests for heteroscedasticity and serial correlation.

Test	Error process	Test statistic		
		FI_Z	FI_MMX	FI_SOFTMAX
Modified Wald (χ^2)	Heteroscedasticity	11,356.53***	19,203.34***	14,821.73***
Wooldridge Test (*F*-test)	Serial correlation	19.28***	19.783***	19.347***

**** meaning significant at 1% level.*

TABLE 4 | Pearson (2004) CD test.

Variable	CD-test statistic	*p*-value
INC	29.564[a]	0.000
URB	39.540[a]	0.000
ENE	8.674[a]	0.000
IND	7.654[a]	0.000
TRADE	5.904**	0.007
FDI	5.321[a]	0.000
CO2	10.590[a]	0.000
FI_Z	29.298[a]	0.000
FI_MMX	21.589[a]	0.000
FI_SOFTMAX	29.690[a]	0.000

[a]*This shows that the null hypothesis has been rejected at a 1% level of statistical significance. To calculate the aggregate micro finance score, PCA was used to standardize profitability ratios using the z-score, min-max, and soft - max methods, correspondingly. Authors' computations are the source of this information.*
*** meaning significant at 5% level.*

of income per capita was added since a greater income makes it easier to obtain financial services, lowers the barriers to doing so, and increases demand for such services (Khatibisepehr and Huang 2008). Controlling for the increase in the population, we hypothesised that rising populations lead to an increased segment of the population load, which limits the accessibility of financial institutions to the unbanked and underbanked (Perotto and Filipo, 2021). It is necessary to incorporate the institution cost to revenue (in percent) in order to manage the expense of capital structure, since the research has shown that institution expenses are a factor in economic developement (Nodelman et al., 2005). With the help of (Zhang et al., 2013), we incorporated a social development scale and predicted that a greater degree of awareness would lead to more economic developement since it would reflect a nation's better success in these areas. In accordance with previous research, we also implemented capital controls as a fictitious limitation on financing (Ratnaweera et al., 2004).

4.2 Regression Analysis

Hoechle (2007)'s method yielded the estimated findings, which are shown in **Table 4**. Improvements in the other potential determinants, particularly earnings, resource utilization, urbanisation, and financial inclusion, lead to greater levels of carbon emissions in Europe, regardless of export growth. The findings demonstrate this.

The outcomes are shown in **Tables 5a**, **5b**. These show what the economic developement index, financial outreach, and use look like when just monetary policy is taken into account as a linear regression. show what devaluation and operating expenses look like when they're both under control at the same time. As additional regression models, rising prices, operational costs, and capital adequacy accumulation are shown in columns 7–9. The conclusion—that the availability of international banks lowers economic developement but its connection with banking sector development increases financial inclusion—is strong in all scenarios. Our data shows that adjusting for additional regressors has no effect on our statistics. There is a significant impact on pollutants from rising incomes, which suggests that as nations in Europe grow, greenhouse gases will increase. According to (Bartlett and Cussens 2017), growth in the economy does not presuppose ecological sustainability, which seeks to enhance the ecological integrity in the area. This result supports their findings. The adoption of appropriate technology seems to be neglected in Europe's product development (Khanteymoori et al., 2018).

EC, urbanisation, and industrialisation are all anticipated to have a beneficial impact on climate change, according to previous research (for instance. Local energy consumption now accounts for approximately 27% of export growth and is expected to increase even more in the coming years as a result of impressive industrial prosperity. As a result of the Asian upswing, increasing urbanisation, and industrialisation, there is an increase in production supply and consumption. There is an increase in the need for energy due to increasing economic development throughout Europe, especially in areas like manufacturing of products. By 2035, carbon emissions are estimated to increase for almost 75% of the increase in Europe's energy demands, raising CO2 emissions of carbon dioxide 60%. If FDI has a negative impact on carbon dioxide emissions, it is because foreign investors want to circumvent pollution laws in their native nations. Due to the FDI industry having a detrimental effect on Italy's long-term development, biodiversity will be severely harmed and the pace of growth will be less viable. There is some evidence to suggest that dirty businesses are moving from the industrialised nations to the poor world in order to get around more stringent standards, according to this study (Gu et al., 2019; Neri et al., 2020).

Opening Europe's economy to free trade has been shown to decrease emissions of carbon dioxide. Trade deals, in particular, may help countries better address sustainability issues (Alekseichuk et al., 2016; Hanslmayr et al., 2016). Ecological products and services may be made more widely available at lower costs by lowering or eliminating protectionist measures. The TPP deal, for example, is anticipated to help emerging economies move into relatively clean, less destructive sectors and transportation to minimal paths, thus helping actions to resolve global problems like global warming (Antal et al., 2017). Financial inclusion, one of our main

TABLE 5A | Estimation analysis.

Dept variable: CO2	Pooled OLS/WLS regression			Fixed effects (within) regression			GLS random effects regression		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
INC	0.721***	0.711***	0.643***	2.781***	2.873***	1.421***	0.834***	0.892***	0.892***
	(0.021)	(0.011)	(0.015)	(0.081)	(0.081)	(0.081)	(0.031)	(0.027)	(0.031)
ENE	0.532***	0.509***	0.523***	2.121***	2.832***	2.671***	2.634***	1.041***	2.651***
	(0.051)	(0.062)	(0.051)	(0.038)	(0.048)	(0.039)	(0.043)	(0.061)	(0.054)
URB	0.702***	0.821***	0.701***	0.541***	0.552***	0.487***	0.411**	0.312***	0.267**
	(0.019)	(0.018)	(0.018)	(0.121)	(0.111)	(0.112)	(0.219)	(0.092)	(0.112)
TRADE	−0.091***	−0.122***	−0.091***	−0.178**	−0.102**	−0.102**	−0.321*	−0.134*	−0.141*
	(0.031)	(0.019)	(0.018)	(0.042)	(0.036)	(0.041)	(0.071)	(0.067)	(0.058)
FDI	0.018**	0.011**	0.011**	0.002	0.003	0.004	0.003	0.002	0.001
	(0.004)	(0.004)	(0.003)	(0.005)	(0.001)	(0.002)	(0.003)	(0.002)	(0.002)
IND	0.511***	0.311***	0.521***	0.128***	0.167***	0.178***	0.141***	0.140***	0.211***
	(0.039)	(0.034)	(0.044)	(0.049)	(0.0213)	(0.049)	(0.038)	(0.028)	(0.042)
FI_Z	0.059*			0.011***			0.039***		
	(0.041)			(0.004)			(0.005)		
FI_MMX		0.411**			0.078***			0.219***	
		(0.321)			(0.021)			(0.028)	
FI_SOFTMAX			0.401*			0.111***			0.212***
			(0.316)			(0.019)			(0.031)
CONST	−7.765***	−8.654***	−8.654***	−11.652***	−11.786***	−17.786***	−7.809***	−7.986***	−8.654***
	(0.087)	(0.213)	(0.287)	(0.896)	(0.876)	(0.876)	(0.543)	(0.674)	(0.543)
Observations	289	289	289	289	289	289	289	289	289
Number of groups	21	21	21	21	21	21	21	21	21

** meaning significant at 10% level.*

TABLE 5B | Robustness analysis.

Variable	FOLS	FMOLS
INC	31.564[a]	26.224[a]
	(0.000)	(0.000)
URB	23.210[a]	16.610[a]
	(0.001)	(0.002)
ENE	0.374[a]	0.236[a]
	(0.003)	(0.002)
IND	2.643[a]	2.231[a]
	(0.002)	(0.001)
TRADE	2.973**	2.543**
	(0.006)	(0.005)
FDI	2.321[a]	2.654[a]
	(0.000)	(0.000)
CO2	7.320[a]	3.540[a]
	(0.000)	(0.000)
FI_Z	11.298[a]	6.432[a]
	(0.000)	(0.000)
FI_MMX	21.589[a]	13.543[a]
	(0.003)	(0.003)
FI_SOFTMAX	12.320[a]	4.210[a]
	(0.002)	(0.003)

[a]This shows that the null hypothesis has been rejected at a 1% level of statistical significance. To calculate the aggregate micro finance score, PCA was used to standardize profitability ratios using the z-score, min-max, and soft—max methods, correspondingly. Authors' computations are the source of this information.
*** meaning significant at 5% level.*

variables, has been linked to increased emissions of carbon dioxide in Europe, according to our research. With better access to capital, residents in Europe could have bought too many things like cars and trucks, kitchen appliances, air conditioning units, and TV screens during the period under analysis. These products, with their prevalent usages, generate higher utilisation of coal and oil and lead to increased carbon dioxide emissions in the area. According to our findings, there have been no linkages between anthropogenic global warming policies and economic development efforts. Using various economic development indicators and other linear regression with Cleary and Haug confidence intervals, the findings are fundamentally stable.

4.3 Robustness Analysis

The interests of local governments range from regional interests to the interests of officials, while regional interests are mainly characterized by the improvement of the quality of green development. Since entering the new era, the leading social contradiction has transformed into the contradiction between people's growing need for a better life and unbalanced and inadequate development, and the best vehicle and optimal strategy to dissolve this contradiction is to strengthen social governance, of which green governance further strengthens the quality of development with a balance of ecological, economic, political, cultural and social construction. Research by relevant scholars has also highlighted the vital contribution of green governance to high-quality development. Doyle confirms the positive effect of green governance on green quality development based on policy analysis, emphasizing that green governance expands the green public sphere across political boundaries and lays the foundation for the green transformation of society.

From theory to reality, few studies have considered the impact of peer effects on green governance decisions and benefits when analysing the green governance activities of local governments. As a "rational person," the local government is bound to be

perturbed by the decisions of its group or even a side group. Therefore, in some areas where the environmental basis of green governance is similar and the incentive logic converge, there will inevitably be dependence and consistency in behavior and decision-making. In contrast, some areas with heterogeneous environments and incentive logic may be characterized by imitation and following, tending to cohere with more successful groups and have superior externalities such as green governance efficiency. In short, the characteristics of local governments, the environmental basis of green governance, and the incentive logic make green governance peer effects. However, whether this effect produces positive social influence or inhibits green social development and produces a depletion of governance resources needs to be further clarified from the motivation of green governance to control the direction of the peer effects of green governance.

5. CONCLUSION AND POLICY IMPLICATIONS

According to the findings of this research, almost all of the variables examined (earnings, power consumption, urbanisation, industrial growth, foreign direct investment, and financial inclusion) contributed to increased carbon dioxide emissions in Europe between 2006 and 2018, while financial liberalisation appeared to have lowered air pollution. The fact that economic development has a detrimental impact on human health does not mean that we must stop promoting it. Alternatively, governments must make it possible for customers to get the money they need by focusing on the right kinds of economic development and availability. Taking green finance as an example, America is a major participant with obvious political significance (Zhang et al., 2020). As a result of the "Sustainable Green Economy" proclaimed on 16 April 2010, foreign banking firms are now required to support the advancement of an ecofriendly, low-carbon economic system, enhance the accuracy and reliability of accounting amenities, provide alternative credit financing activities, and keep improving the green credit customer's ability to meet their obligations (Smith et al., 2011). With a sustainable economic development programme, the danger of green financing should be reduced (Neuling et al., 2017).

Economic development measures must be coordinated with climate change policies in all nations in the area, including the United States. The United Nations framework convention on climate collaboration has been promoted most actively by Europe (Polanía et al., 2012). Because of the International Agreement, countries in Europe implemented the Continental Environmental Trading Platform in 2005, despite significant political and philosophical differences (Hanslmayr et al., 2016).

As CO_2 greenhouse gas emissions continue, policymakers must promote environmental financing that is more accessible and equitable for those who are underprivileged or financially excluded. Consumers, microenterprises, and entrepreneurs should have access to banking services so they can reduce carbon dioxide emissions at the grassroots. It is important to highlight that, among several other aspects of the 2030 Agenda for sustainable development, significant governmental and non-governmental expenditure is critical for the transition to a low-carbon green economy. In the same way that all other past research has flaws, this one has a few as well. For starters, caused by a lack of data recorded, some critical factors of ecological sustainability, such as social and economic sustainability and global warming sensitivity, could not be seen as estimation methods. Besides which, to adequately capture the position of 'power generation legislation, even more exploration may be required to provide opinion on the matter to the simple interaction of carbon harm and compliance issue tracking with hydrocarbon rental income and other alternative fuels To compensate for these drawbacks, the report makes many suggestions for future research to help close research gaps linked to power demand, economic development, and (Carbon dioxide) pollution, as well as environmental rents. That's why research into the links involving economic development and emissions of carbon dioxide at the national and subnational levels is strongly suggested.

According to research, as the economy grows, so does coal energy use, and this has the unintended consequence of slowing sustainable growth. This possibility argues to authorities that reducing greenhouse gas emissions or limiting hydrocarbon use will lead to a decrease in financial inclusion, further thwarting UN Millennium Development Goals initiatives and green economies. As a consequence of this finding, the researchers have identified the accompanying policy implications. An approved regulatory body may evaluate managing to align organisations for the maximum advantage of improving 2030 Agenda 2030 because greenhouse gas emissions are heavily affected by carbon dioxide emissions. Aside from that, the generation of renewable and alternative energy could conceivably be prolonged, as well as the role of carbon dioxide in contributing to habitat destruction might be effectively controlled. Furthermore, imposing structural frameworks on carbon dioxide production would result in a quantifiable stability in GHG emissions, which would have a ripple effect on decreasing carbon dioxide emissions in the emerging economies of the European region.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HL: Original draft; K-TW: Literature; KK: revision; TT: Supervision; TN: Methodology; TP: Data Curation.

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Integrating the Role of Green Fiscal Policies With Energy Prices Volatility and Energy Efficiency: Presenting a COVID-19 Perspective

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Energy and other related sectors are changing in China. This study attempted to estimate the energy product price volatility with energy efficiency during COVID-19 with the role of green fiscal policies. For this, we applied unit-root tests, ADCC-GARCH, and CO-GARCH techniques to infer the study findings. The results showed that energy price volatility was significantly connected until 2018. More so, the green fiscal policies were significantly connected between energy product price volatility and energy efficiency during COVID-19 (2019–2020). From energy products, the crude oil price volatility was significant at 16.4%, heating oil volatility was significant at 18.2%, natural oil price volatility was 9.7%, gasoline price volatility was 28.7%, and diesel price volatility was 34.1% significant with energy efficiency, due to the intervening role of green fiscal policies. The findings of this study are robust in comparison to previous studies. Multiple stakeholders can take guidelines from the findings of the recent study. As per our best understanding and knowledge, if suggested recommendations are implemented effectively, these results will help to enhance energy efficiency through green fiscal policies in the post-COVID period.

Keywords: COVID—19, energy consumption, energy efficiecy, price volatility, energy products, green fiscal policies

INTRODUCTION

Several nations have their own clean energy sector strategy plans. Greenhouse gas mitigation and aggressive decarbonization goals have necessitated fast investment development in renewable energy industries. In order to encourage the fast expansion of the energy sector, the Chinese government has implemented a number of green economic measures, such as the use of government subsidies and tax rebates. As a result of China's fiscal incentives, stringent environmental regulations, and investment-consciousness improvement, the Chinese green energy market has grown significantly, and China has become a global leader in renewable energy industries.

Many academics have shown that various macro-perspectives, including tax incentives and subsidies, may spur investment in renewable energy sources. For renewable energy projects, high investment costs, the availability of capital, subsidies, and stable market conditions are key considerations. Future developments in low-carbon energy technologies as well as integration of

capabilities and feed-in tariffs make renewable energy investment viable. The welfare of green investment projects might be harmed by free-riding and overheating of green investment subsidies. Reducing subsidies for fossil fuels in the Middle East and North Africa might lead to stronger GDP growth per capita and more employment and labor force participation. Subsidies for the growth of China's renewable energy vehicle sector and a reduction in the country's vehicle emissions have been a success.

For energy producing companies, the efficiency of renewable energy investment is determined by a number of micro basic elements. Higher energy price uncertainty reduces the responsiveness of investment, while increasing energy prices have a negative effect on investment in the industrial sector. Renewable energy companies in the United States, Germany, Mexico, and Brazil vary in economic value due to variances in capacity adjustment and market power rents. Investor preferences and demand, knowledge base, and asset price of socially responsible investments all play a significant role in enabling the investment inputs of these assets. New energy companies' investment efficiency is influenced by both macroeconomic and company-specific factors. The empirical findings highlight the potential worth of renewable energy companies.

Prices of products are variable (Pindyck, 2004). This is evident where the energy products prices have faced a downturn in the recent decade (Cabrera and Schulz, 2016). Such volatility, although significant, is not unprecedented in the last century with many major price cycles (Gilbert, 2006). Over the last 2 decades, global commerce in products has increased more than seven times and export proportions have grown (Williamson, 2012). The magnitude and the pattern of growing export concentrations of these price fluctuations have revived attention in the quantitative impacts of price shifts in products (Bakas and Triantafyllou, 2018). Two key issues are whether or not change in products prices is advantageous or expensive. In other words, in what way should fiscal strategy react best. The usual assumption is that domestic reserves on the earth are known (Judit et al., 2017). There is no mechanism through which companies may increase current reserves by exploring. Existing reserves are also not depleted. These two channels, which are highlighted in the literature on natural resources, are summarized by assuming a technology for the extraction of Cobb-Douglas with exogenous technological changes in reservations. There is minimal difference between natural resources and other economic sectors (Dwyer et al., 2011).

We see a richer supply model by incorporating exploration, depletion, and reserve shortage into a tiny commode exporting economy otherwise typical (Onour and Sergi, 2011). The source of investments is treated as the main variable in contrast toward the view of reserves as fixed and invariant to changes in products prices (Lence and Hayes, 2002). Companies may spend in exploration to discover new deposits (Gilbert and Mugera, 2014). The fact that the extraction of assets leads to their depletion is also taken into consideration (Combes and Guillaumont, 2002). We investigate the extra resource subtleties that are relevant and aimed at the exhibition of product valuing volatility shockwave propagation with the effects on national wellbeing and the optimum strategy directions (Arezki et al., 2014).

China's energy production sector has experienced significant changes decades after the introduction of green revolution technology and price support government policy (Trolle and Schwartz, 2009). In consequence, China has gone from being a country with a food deficit to a food surplus nation. Many energy products are still affected by government restrictions on production, supply, and distribution (Kroner et al., 1995). Future products trade has a long history in China and began in 1857 with cotton. It remained for many decades in a hibernating condition owing to concerns about the potential advantages of derivatives and fear of needless speculation in vital products (Ahuja et al., 2006). After independence, numerous governmental efforts for the protection of the energy sector negatively impacted the development of markets for energy goods. The Essential Products Act of 1955 envisioned price and movement protection for different energy products, in particular food grains such as paddy, wheat, raw grains, and pulses, in order to preserve the interests of both manufacturers and consumers.

It was believed that throughout the development of economic liberalization, there was a necessity for energy products reorientation policies and regulations. Similarly, Swaray (2007) suggested that futures trade be reintroduced in most key sector products. In July 2000, the National Energy Policy stated that external and domestic market reforms *via* the implementation of a future trade/market system and dismantling of all energy products market controls and restrictions should be implemented (Moledina et al., 2004). Consequently, prior to this, the Government of China published notices and allowed futures trading for a broad range (excluding options trading) of farming products (Choi and Hammoudeh, 2010). There are now four national and regional levels of products markets in China allowing for the trading of derivative farming products (Arezki et al., 2012).

Disordered sales of energy goods soon after harvest due to shortage of the ability of farmers to wait for an appropriate moment for pay prices and the uncertainty in potential future pricing are consistent significant issues both for producers and consumers (Hegerty, 2016). As noted in the literature, energy future contracts assist to achieve the intent considered with the study topicality. Two essential administrative tasks include price discovery and price risk management for the particular products (Mensi et al., 2013). This helps producers since they have a good notion of pricing that will prevail in the future and thus their limited available resources may be allocated among different competitors. It offers food processors and consumer notion of pricing at which the particular products are accessible at a future time point.

Exogenous resource models contradict data for SCEs in numerous ways. Notable is the fact that reserve growth is not related to price growth (Naylor and Falcon, 2010). Empirically, price increases, research, and subsequent discovery of new deposits are beneficial. When prices are high, companies are more motivated to find new reserves, and as not all expeditions are successful, they do find new deposits. Second, traditional

models predict significant positive change in both pricing and extraction simultaneously (Creti et al., 2013). In the data, the present correlation is close to zero, and the growth lag is negative where prices first rise and by the time extraction increases price growth is already declining back to baseline (Cashin and McDermott, 2002). We show that searching for new resources and building new mines are major adjustment margins that postpone the response to extraction, which better explains the data correlations (Du et al., 2011).

Exploration and depletion better reflect resource price fluctuations (Kang et al., 2017). It is possible to achieve a good balance between price growth and exploration growth, and exploration growth and reserve expansion (Brooks and Prokopczuk, 2013). So there is no current relationship between rising prices and increased extraction, no contemporary link between the real exchange rate and extensive products and labor mobility. The results emphasize exploration, which leads to new resources and increased production potential (Power and Turvey, 2010). When resource prices increase, businesses ramp up exploration, and if new reserves are found, the production system can never slow down (Alemzero et al., 2021). This increases complementarity in extraction, exploration, investment, and demand for mining employees, allowing for higher resource sector development in price increases and contraction in price decreases (Li et al., 2021a). So long as production returns are stable and there is no pricing power on global markets, reserve stockpiles and the business are unpredictable (Iqbal et al., 2021a). It is true that endogenous reserves amplify the effect of price changes (Li et al., 2021b).

The remainder of this work is structured as follows. *Literature Review* provides a literature summary. *Data and Methodology* discusses empirical methods. *Results and Discussion* contains the data and descriptive statistics. *Conclusion and Implications* provides empirical results and analyses.

LITERATURE REVIEW

This research has quadrupled its contribution to the literature. First, we provide new evidence of the heterogeneous volatility dependence between crude oil and China's energy futures market under different market conditions (Iqbal et al., 2021b). No precise correlations in violent/stable market circumstances are defined despite many studies on the volatility linkages between crude oil and energy markets. So we give a comprehensive review of the heterogeneous volatility spillovers using the QQR technique (Ahmad et al., 2021). Asymmetric volatility is linked to violent and stable markets, the results suggest. Moreover, extremely high or low volatility oil has significant effects on the environment.

Since the financialization of products, several studies have examined how products are linked together (Rl and Mishra, 2021)). Products markets need an understanding of oil and energy products fundamentals (Umar et al., 2021). For example, several previous studies examined the potential interrelationships between energy and energy and metals markets (Ouyang and Zhang, 2020). There is evidence that the rise in food costs is linked to the usage of biofuels, which replace oil-based products. Prices of energy inputs may also be affected by oil price fluctuations (Tiwari et al., 2021). Agribusiness relies heavily on oil for its energy needs, thus oil price fluctuations may affect energy products. Shipping costs for energy products may also be affected by oil prices (Michail and Melas, 2021).

Previous research has shown that increasing biofuel production justifies increasing the effect of oil prices on energy products (Vu et al., 2020). For a profitable alternative asset, products may be used to diversify portfolio risks. Energy products markets are responsive or indifferent to oil price changes, according to some researchers (Ali and Khan, 2020). For example, does the form of an oil shock affect how transmission affects from the oil market to other products markets? The effect of risk, demand, and supply shocks on the products markets should be studied (Sharma and Kumari, 2021). Research shows that the variables examined respond differently to oil shocks depending on the source (Palazzi et al., 2020).

Several studies have been conducted to mimic crude oil price volatility characteristics. The structural dynamics of oil future volatility was examined by Sun et al. (2021). For the European Brent and WTI markets, Cheong studied volatility persistence and leverage effect (Liang et al., 2021). The studies also explained the predicting capabilities of an SV model by adding the system change character. For example, Chan and Grant found that SV models outperform GARCH models in terms of energy price dynamics. Fasanya and Odudu (2020) used the autoregressive benchmark model to show how crude oil volatility may help forecast short-term inventory volatility. A fat tail distribution, clustered volatility, and mean reversal are all accepted characteristics of crude oil prices (Kotyza et al., 2021).

Contrary to popular belief, products index traders (CITs) are not speculators (Asgari et al., 2020). Traditional speculators, also known as long-term investors, were significantly decreased in impact, despite the empirical research rejecting Master's theories (e.g., Stoll and Whaley, 2010; Irwin and Sanders, 2012; Hamilton and Wu, 2015). These differences in investment styles may have varied effects on market outcomes. The market is expected to defeat short-term speculators who, unlike CITs, buy and hold long positions in near-term contracts (Berman et al., 2020). If speculative trading stabilizes or destabilizes (products) prices, the theory is unclear. To summarize, speculative trading stabilizes prices by buying low and selling high (Zhang et al., 2020). Prices would be destabilized if speculators bought high and sold low, but they would eventually leave the market anyhow (Oscar et al., 2020).

The relationship between biofuel and energy products prices is increasingly being studied using econometric methods by academics. The majority of studies focus on price interdependencies (Erten and Ocampo, 2021). Few have examined market transmission and volatility. Most studies on biofuels and energy products pricing use data from Brazil and the US since they are significant producers of biofuels (Roman et al., 2020). However, the European market lacks empirical risk assessment (Levi et al., 2020). An overview of recent studies on biofuel price transfers is provided below. In an appraisal by Yuan et al. (2020), they investigate non-linear adjustment to long-term balance between crude oil, ethanol, and petrol in Brazil

using Bayesian techniques. In long-term equilibrium between each price pair, they found a link between oil, petrol, and ethanol. Identical conclusions are reached. As a result of changing economic and political forces in Germany, Olagunju et al. (2021) utilize a VECM regime-dependent Markov switch. Overall, they find that crude oil drives biodiesel prices, which drives vegetable oil costs.

We concentrate on exploration and depletion since these are probably essential in seizing the spread of product tremors (Guhathakurta et al., 2020). In partial balancing models for natural resources and the opportunity cost of depletion, it is essential to understand how resource companies adapt to price fluctuations. Macroeconomic reserves may also be significant (Vivian and Wohar, 2012). With the restricted spread of product value tremors, when fixed, the relationship (Ezeaku et al., 2021). Given the adaptation occurring by the quantity of output when products prices vary, the study examined whether extra wealth benefits related with the finding of novel reservations may help explain data on products price volatility with macro-economic performance (Regnier, 2007).

Similarly, Manogna and Mishra (2020) examined unidirectional volatility transmission. These spills range from basic pricing to catfish prices, and they used an exponential GARCH model to investigate them. An analysis of the spillovers between energy input costs and retail food prices was carried out by Apergis and Rezitis (2003a). Their findings indicate that energy input and output volatility affect food price volatility. Protection is required because to the volatility of production prices caused by own and price volatility. Using a DCC-GARCH-multivariate model, Zhang et al. (2009) examine price transmissions and volatility spillovers across weekly US ethanol, corn, diesel, gasoline, and oil prices. Prices of energy products were shown to be volatile, but not ethanol prices (Apergis and Rezitis, 2003b). Accordingly, the energy markets are seeing increasing volatility. Price changes are ignored. Encoding products correlations into distances is the goal. They were only weakly related before the 2008/2009 food crisis. The bonds deepened during and after the food crisis (Askan et al., 2020). The petroleum, biofuel, and energy products industries have been more intertwined in recent years, according to those studied (Pradhan et al., 2021).

DATA AND METHODOLOGY

Green Fiscal Policies in China

As worldwide environment change revision and energy security anxieties increase, the Chinese government has applied government subsidies and tax rebate policies to inspire the fast development of renewable energy industries; the beneficial effects of these fiscal policies indicate theoretical value and policy implications. Subsidies and tax breaks from the government are becoming more important in alleviating the lack of investment in renewable energy companies and increasing their investment efficiency.

Two new research topics arise as a result of this change:

1) How much of a difference does it make if we encourage investment in renewable energy firms?
2) Is the use of tax incentives and subsidies to encourage renewable energy companies to invest more efficiently a factor?

By focusing on the effects of firm-specific characteristics, energy prices, and investor preferences on renewable energy firms' investment efficiency, as well as the financial performance impacts of subsidies and tax policies, this article aims to fill in knowledge gaps from the analysis of the preceding articles.

There has been a lack of knowledge of the important effect of government subsidies and tax rebates on increasing renewable energy enterprises' investment efficiency and identifying investment gaps in the renewable energy sector at a micro-level in prior literature studies. Renewable energy enterprises' investment efficiency gaps may be impacted by both firm-specific factors: varied government subsidies and tax rebates policies. Renewable energy companies must determine if government subsidies and tax breaks really encourage excessive development, as well as whether factor inputs really do help to improve investment efficiency. Government and company leaders are particularly interested in the relationship between green fiscal policies and the purpose of firms to improve factor investment efficiency. There are two major fiscal policy issues in emerging and developing countries: the use of government subsidies and tax refunds to supplement or replace private component investment.

In contrast to renewable energy enterprises in industrialized nations, Chinese renewable energy firms have distinct investment gaps because of their unique institutional foundation and market conditions. Government policymakers and managers can make better investment choices for renewable energy businesses by evaluating the investment efficiency of renewable energy enterprises and monitoring the implementation efficiency gaps of renewable energy fiscal policies.

Study Data

NCDEX, a well-known agri-products marketplace, provided the daily closing futures prices for six key energy products (2004–2018). They remained chosen because they represent over 75% of all energy futures traded at NCDEX in terms of value. While collecting adjusted closing prices of different products in spot souks, that include the delivery point for futures contracts, the NCDEX website was also utilized. **Table 1** shows expressive data for spot and stocks for several products. ADCC-GARCH and CO-GARCH tests were used to compare the mean values of futures price volatility (**Table 2**).

Study Model and Estimation

The use of test statistics has increased in the research of energy products prices volatility, which is supported by the literature review (Ismail et al., 2017; Hau et al., 2020; Tariq et al., 2020). Co-integration efficacy in predicting price confluence to assess futures trading effectiveness has been investigated in other studies. Price coordination between spot and futures prices is required for markets to function effectively. It ensures that the two series are kept in equilibrium over time (Zafeiriou et al., 2018). The absence of serial correlation in a futures market indicates that futures prices have little connection to cash price fluctuations, implying that the

TABLE 1 | Daily energy products spot prices and futures prices.

Products	Legend	Mean	Min	Max	SD	CV%	F-value	*p*-value
Crude oil							5.251*	0.000
	Products price	0.1274	0.0615	0.0107	0.0229	32.57		
	Futures price	0.6714	0.0355	0.02015	0.0107	38.99		
Heating oil							9.913*	0.000
	Products price	0.2328	0.0544	0.1272	0.5378	26.71		
	Futures price	0.2497	0.0084	0.1199	0.8692	16.68		
Natural oil							3.315*	0.000
	Products price	0.3129	0.1143	0.2967	0.9813	89.99		
	Futures price	0.8792	0.0816	0.8769	0.7149	14.81		
Gasoline							8.257*	0.000
	Products price	0.8477	0.0852	0.5589	0.5833	27.63		
	Futures price	0.762	0.0236	0.0432	0.1216	11.03		
Diesel							1.053*	0.000
	Products price	0.4254	0.2022	0.6662	0.1786	12.81		
	Futures price	0.2023	0.3192	0.5889	0.5561	11.57		
Brown coal							8.775*	0.000
	Products price	0.2384	0.0106	0.2317	0.1111	17.97		
	Futures price	0.6852	0.0114	0.9312	0.1054	36.75		

**significance at* p*-value < 0.05.*

TABLE 2 | Energy prices turnover and energy efficiency with respect to gross domestic product.

		Energy futures turnover			
Year	**GDP (in billions)**	**Energy GDP (in billions)**	**Volume (in billions)**	**Value (in billions)**	**Futures markets turnover (in billions)**
2004–2006	30,307	25,914	132 (6.5)	44 (1.7)	60.4
2006–2008	27,055	10,017	554 (2.1)	170 (5.8)	233.9
2008–2010	14,059	11,707	734 (1.0)	967 (1.4)	261.01
2010–2012	19,885	6,720	104 (15)	141 (3.6)	130.14
2012–2014	19,500	8,203	816 (3.3)	148 (7.3)	143.25
2014–2016	33,600	71,791	496 (0.7)	152 (4.3)	556.91
2016–2018	43,014	35,1012	176 (4.9)	471 (0.8)	230.00
2018–2020	45,901	34,510	101 (3.5)	222 (0.56)	171.03

market is relatively inefficient. The current study follows the same approach as earlier work.

After establishing how the spot prices of energy future contracts are interrelated, the orientation of the connection must be determined in order to show causality. Prior to connectedness examination, the study has operationalized the unit root analysis (see **Table 3**). More so, to determine the stationary condition in the empirical model of study, the autoregressive analysis technique was tested. The series is in a stationary condition if it has no dependency on time. The normality of all futures and spot price series was evaluated using unit root tests utilizing the ADF and PP techniques, which can deal with non-parametric data (**Table 4**). Using this equation, a regression equation was calculated to evaluate the stationarity of futures and spot prices:

$$\Delta Y_t = \beta_0 Y_{t-1} + \sum_{I=1}^{T} y_i \, \Delta \, Y_{t-1} + \varepsilon_{it} \tag{1}$$

The tests below show how we estimated the lag length using a constant intercept and Schwarz information criterion. A co-integration test was used to assess whether or not non-stationary series are connected by length in an equilibrium connection. This study used the probabilistic approach, which employs Johansen's co-integration tests, to estimate the long-term forecast of spot and futures prices (**Tables 5**,**6**). The Johansen co-integration test, which estimates an n-dimensional vector under the premise of an n-dimensional vector Xt with integration of order I (1), may be used to estimate a vector autoregressive model. Johansen and Juselius (1990) improved the model by adding an error correction that was visualized as follows:

$$Y_t = c + \sum_{I=1}^{k} y_i \; \delta Y_{t-1} + \varepsilon_{it} \tag{2}$$

Two Lagrange multiplier test statistics are presented by the traces and maximum eigenvalues of the residual vectors. The trace statistics check to see whether r equals k. The maximum eigenvalue statistics is used to determine if a series is trending over time or has reached its stationary point.

$$\Delta Y_t = \mu + \sum_{I=1}^{k} y_i \; \delta Y_{t-1} + \varepsilon_{it} \tag{3}$$

On the advantage of employing two checks for serial correlation, there are many points of view. While Johansen

TABLE 3 | Unit root analysis.

		ADF		PP	
Products	**Legend**	**Level**	**1st diff**	**Level**	**1st diff**
Crude oil					
	Products price	0.69 (0.455)	0.27* (0.000)	0.81 (0.895)	0.44* (0.000)
	Futures price	0.17 (0.111)	0.77* (0.000)	0.25 (0.662)	0.64* (0.000)
Heating oil					
	Products price	0.19 (0.351)	0.76* (0.000)	0.65 (0.707)	0.96* (0.000)
	Futures price	0.85 (0.078)	0.58* (0.000)	0.29 (0.559)	0.63* (0.000)
Natural oil					
	Products price	0.56 (0.907)	0.78* (0.000)	0.55 (0.603)	0.99* (0.000)
	Futures price	0.21 (0.321)	031* (0.000)	0.89 (0.170)	0.83* (0.000)
Gasoline					
	Products price	0.85 (0.103)	0.24* (0.000)	0.09 (0.131)	0.28* (0.000)
	Futures price	0.42 (0.885)	0.85* (0.000)	0.63 (0.119)	0.99* (0.000)
Diesel					
	Products price	0.86 (0.900)	0.67*(0.000)	0.72 (0.322)	0.57* (0.000)
	Futures price	0.79 (0.830)	0.88* (0.000)	0.64 (0.343)	0.63* (0.000)
Energy efficiency		0.43 (0.777)	0.67* (0.000)	0.39 (0.236)	0.41* (0.000)

**significance at* p*-value < 0.05, ADF (Augmented Dickey-Fuller test), PP (Phillip Person test).*

TABLE 4 | Co-integration test.

		Trace values		Maximum eigenvalues	
Products		**Trace**	**Significance**	**Trace**	**Significance**
Crude oil					
	H_0: $r = 0$	0.65	(0.000)	0.88	(0.000)
	H_0: $r \leq 1$	0.71	(0.000)	0.22	(0.000)
Heating oil					
	H_0: $r = 0$	0.95	(0.000)	0.57	(0.000)
	H_0: $r \leq 1$	0.58	(0.000)	0.99	(0.000)
Natural oil					
	H_0: $r = 0$	0.69	(0.000)	0.53	(0.000)
	H_0: $r \leq 1$	0.23	(0.000)	0.81	(0.000)
Gasoline					
	H_0: $r = 0$	0.83	(0.000)	0.93	(0.000)
	H_0: $r \leq 1$	0.48	(0.000)	0.39	(0.000)
Diesel					
	H_0: $r = 0$	0.89	(0.000)	0.73	(0.000)
	H_0: $r \leq 1$	0.83	(0.000)	0.443	(0.000)
Energy efficiency	H_0: $r = 0$	0.74	(0.000)	0.129	(0.000)
	H_0: $r \leq 1$	0.82	(0.000)	0.346	(0.0000)

TABLE 5 | DCC-ADCC findings.

	DCC estimated outputs			ADCC estimated outputs		
	Co-efficient	**Standard error**	**T-stats**	**Co-efficient**	**Standard error**	**T-stats**
Crude oil	0.9165	0.1564	0.3475	0.0529	0.0993	0.0343
Significance	(0.001)			(0.000)		
Heating oil	0.2496	0.0365	0.0397	0.0324	0.0407	0.2781
Significance	(0.000)			(0.000)		
Natural oil	0.1279	0.3398	0.0488	0.9317	0.9029	0.0465
Significance	(0.000)			(0.000)		
Gasoline	0.0103	0.1954	0.0217	0.0541	0.1296	0.0794
Significance	(0.000)			(0.000)		
Diesel	0.0863	0.2558	0.0933	0.2763	0.2207	0.8213
Significance	(0.000)			(0.000)		
Energy efficiency	0.0761	0.3271	0.0441	0.3333	0.1012	0.7681
	(0.000)			(0.002)		

TABLE 6 | Empirical results of ADCC-GARCH estimates.

	ADCC	GARCH
Crude oil	0.961*	0.576*
	(0.000)	(0.000)
Heating oil	0.572*	0.103*
	(0.000)	(0.000)
Natural oil	0.811	0.121*
	(0.000)	(0.000)
Gasoline	0.304*	0.184*
	(0.000)	(0.000)
Diesel	0.814*	0.724*
	(0.000)	(0.000)

and Juselius (1990) studied complex circuits, it was proposed that the trace test may be weaker than the maximum eigenvalue test, as Cheung and Lai demonstrated (1993).

$$\propto_{max} = -T\sum_{i=r+1}^{k}\ln\left(1-\gamma_i\right) \tag{4}$$

Previous values may also assist to clarify the cause, in addressing other factors. For example, it is believed that if Y is Granger causes X, which may then be used to forecast Y, or that Granger will have coefficients. It is worth noting that X is still important after the transmission.

$$\propto_{max} = -T\ln\left(1-\gamma_i\right) \tag{5}$$

The regression **Eq. 5** were created to determine whether X and Y have a short-term connection. Furthermore, if spot and futures prices are co-integrated, causality may be unidirectional or bidirectional. In regression analysis, a test of causation searches for statistically significant information in the lagged values of Y and X. The following are the F-statistic values:

$$Y_t = c_0 + \sum_{I=1}^{p}\beta_i y_i \sum_{i=1}^{p}\beta_j Y_{t-j} + \varepsilon_{it} \tag{5a}$$

Lastly, the causality test was used to assess the connection between futures and spot prices of major farm products, as well as the price direction and future. This (Granger (1969)) technique looks at how much of the variation in one variable can be described by prior values of some other variables, and then tries to figure out whether any past numbers of the other factor may be added to account for the variation in the variable.

Estimation Technique: ADCC-GARCH

The excessive kurtosis in the return distribution may be attributed to the high volatility of petroleum commodities prices and the substantial existence of a conditional variance impact and variance stickiness. As a result, risk management studies often make the unreasonable request that returns are spread regularly.

$$\mathrm{D_t} = \mathrm{diag}\left(h_{1,t}^{1/2},\ldots h_{\mathrm{mt}}^{1/2}\right) \tag{6}$$

As a consequence, other than testing for model superiority, assessing the data to identify the best suitable substantial component is regarded of equal relevance for many investigations (**Table 7**).

TABLE 7 | Robustness estimates: CO-GARCH test.

	U (1)	U (1)	U (3)	U (4)	U (5)
U (1)	0.2825	0.0277	0.2576	0.0833	0.0508
U (2)	0.1127	0.0438	0.0086	0.1247	0.1134
U (3)	0.6572	0.0084	0.5195	0.0836	0.5212
U (4)	0.1617	0.1111	0.0405	0.0314	0.1631
U (5)	0.1745	0.0705	0.1843	0.1966	0.0612
The misplaced medium is B					
	B (1)	B (2)	B (3)	B (4)	B (5)
B (1)	0.0009	0.1151	0.0994	0.2427	0.0191
B (2)	0.5992	0.1866	0.1032	0.0097	0.1475
B (3)	0.1001	0.0099	0.2069	0.8875	0.6202
B (4)	0.0101	0.9093	0.1851	0.0307	0.0727
B (5)	0.1516	0.0326	0.7594	0.0166	0.2742
Estimated outputs of CO-GARCH					
	Crude oil	Heating oil	Natural oil	Gasoline	Diesel
Crude oil	0.0156	0.0543	0.0037	0.0379	0.0816
Heating oil	−0.5316	0.0446	0.1509	0.0228	0.1772
Natural oil	0.2983	0.0708	0.6053	0.0013	0.3025
Gasoline	0.1338	0.0125	0.2352	0.0146	0.3202
Diesel	0.2588	0.0325	0.0326	0.2667	0.0145

$$\mathrm{R_t} = \mathrm{diag}\left(q_{1.t}^{-1/2},\ldots q_{n,t}^{-1/2}\right)Q_t\mathrm{diag}\left(q_{1,t}^{-1/2},\ldots q_{n,t}^{-1/2}\right) \tag{7}$$

The following three-step process is necessary to be effective and to obtain the best accurate distributions of innovation for a certain GARCH class model.

$$\mathrm{h_{i,t}} = \omega_\mathrm{i} + \alpha_\mathrm{i}\varepsilon_{\mathrm{i,t-1}}^2 + \beta_\mathrm{i}\mathrm{h_{i,t-1}} \tag{8}$$

To begin, we remove the innovations from the GARCH model coefficients to get the quasi maximal probability estimation (QMLE) method.

$$Q_t = (1-\theta_1-\theta_2)\bar{Q} + \theta_1 z_{t-1}z_{t-1}^{'} + \theta_2 Q_{t-1} \tag{9}$$

Second, the inventions are reviewed to see if they fall inside a typical normal distribution or not, to use an appropriate diagnostic tool.

$$\mathrm{h_{i,t}} = \omega_\mathrm{i} + \alpha_\mathrm{i}\varepsilon_{\mathrm{it-1}}^2 + \beta_\mathrm{i}\mathrm{h_{i,t-1}} + \mathrm{d_i}\varepsilon_{\mathrm{i,t-1}}^2\mathrm{I}\left(\varepsilon_{\mathrm{i,t-1}}\right) \tag{10}$$

After that, assuming that the innovators do not follow a typical normal distribution, all the information gathered in the second step is used, and only distributions that closely match the tail shape of a given case's discoveries dispersion are chosen for final analysis. However, this strategy presents a contradiction that is difficult to comprehend.

$$Q_t = \left(\bar{Q} - A^{'}\bar{Q}A - B\bar{Q}B - G^{'}\bar{Q}G\right) + A^{'}z_{t-1}z_{t-1}^{'}A + B^{'}Q_{t-1}B + Gz_t^{-}z_t^{'-}G \tag{11}$$

In contrast to the original assumption of a conventional normal distribution, innovations may follow a heavy tailed distribution when the particular technique is applied to

normal GARCH processes—which resembles an IGARCH model.

$$f_t = H_t^{1/2} z_t \tag{12}$$

Due to the fact that this impact is most noticeable in investment rewards, the aforementioned technique is less suited for analyzing energy datasets.

$$A = \Sigma^{1/2} U \tag{13}$$

The GARCH models' discoveries dispersion was checked for normality, and a relative symmetry test was developed by Klar et al. (2012) to supplement the usual goodness-of-fit tests. GARCH models' Gaussian distribution assumption may be tested using their technique, which is supported by their findings;

$$\mathbf{r}_t = m_t + AH_t^{1/2} z_t \tag{14}$$

To test for the suitability of other assumed distributions, such as the Student-t test, they may be appropriately expanded. Furthermore, Sun et al. (2014) established a test for the innovations distribution by comparing the studied tail indices with the Hill tail index estimates in an attempt to overcome the intricacy of the aforementioned troubleshooting technique. It was discovered that the test produced robust findings when utilizing genuine, lengthy, time-series return data from a variety of financial indices, leading to a more thorough and secure estimation of the GARCH model's caudal component (**Figure 1**).

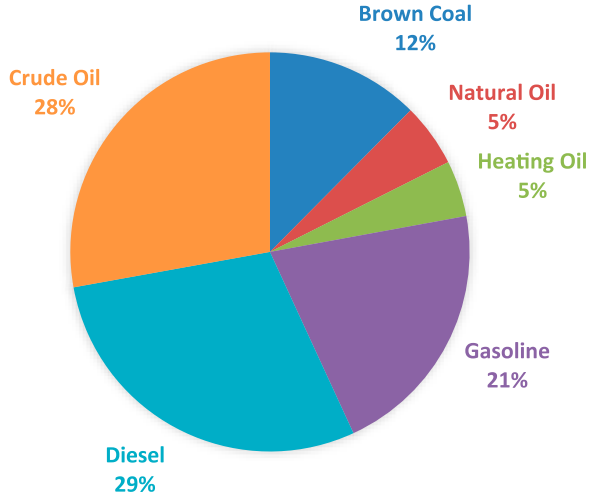

FIGURE 1 | Energy products price volatility (in percentage).

RESULTS AND DISCUSSION

Empirical Results

The data collected by Pindyck (2001) from the petroleum complex over the past 2 decades shows that the futures and spot prices are correlated. This 6-month crude oil futures contract should trade at a discount of approximately 3% below the 6-month spot price. Our findings demonstrate that the trade in Chinese futures affects both market volatility and efficiency but also has an effect on stocks not traded in the market. Although there are still many unknowns in the forecasting of such markets, there is considerable progress in this area as new research continues to be discovered. Several studies have shown that the volatility of the futures market is directly correlated to the volatility of the spot market. Examples of a substantial link between financial markets include contagion, integration, interdependence, co-movement, return, and volatility spillovers.

There is also a desire to see how well all of the used models do in both the pre- and post-disaster cases. In order to generate our forecasts, we rely on the rolling window method, which covers a 48-month period. We have postcrisis forecasting predictions (January 2010 to December 2012) and precrisis forecasting predictions (January 2007 to December 2009) to select from. We are investigating the effect of volatility on the predictability of the S&P 500's volatility (see **Figures 2**, **3**).

More so, the three models using monthly diesel, diesel oil, and cotton RVs (each of which is isolated) demonstrate significant predictive value for the S&P 500 spot. The sample reveals that price information on the products of grains and softs was most effective. Perhaps the reason is the United States is the world's largest producer and exporter of cotton and diesels, which are the country's two most popular exports. FA methodology forecasts outperform FA and average in most cases. In many cases, the FA method is used because it improves a model's accuracy and represents findings with fewer numbers than the original variables.

Based on the data, it is clear that products futures, volatility, and correlation are all connected to financialization, although index futures are more important than non-index futures. As a result, the relationship between the stock market and products is stronger. Markets are a pipeline for global financial factors, influencing products spot price. This research shows that the daily products return's factor structure is weaker than the volatility factor structure, giving insight into volatility and price dynamics.

According to our results, price information on softs and grains has predictive power in regards to the S&P 500 index. The resulted generated from this study should assist market players in comprehending the significance of petroleum and other resource goods volatilities in hedging the risk associated with renewable power commodities. Additionally, speculators may utilize the data offered in the market volatility indices of essential sectors to anticipate clean energy stock market returns. In addition, regulators might rely on the results of this article to design policies trying to reduce the transmission that actually comes from unpredictable commodities markets. The results of this work might also be valuable for researchers engaged in research concerning valuation models, with this advancement also reliant on a better understanding of the linkages among commodities and marketplaces.

There are futures markets for certain energy products. As Telser (1981) writes, futures markets enable price information to be centralized and shared, which, in turn, increases the information in spot prices (according to Powers (1970), Cox

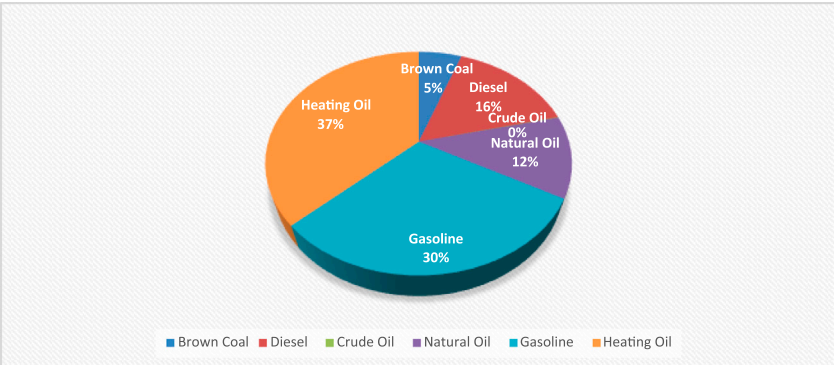

FIGURE 2 | Energy future prices volatility (in percentage).

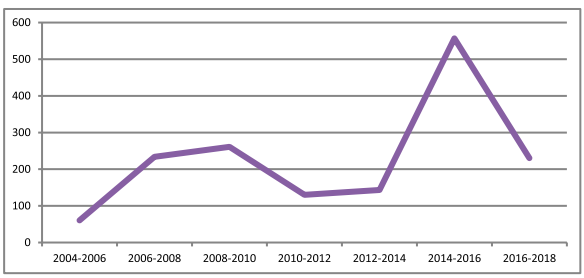

FIGURE 3 | Energy futures contract volatility during the sample period.

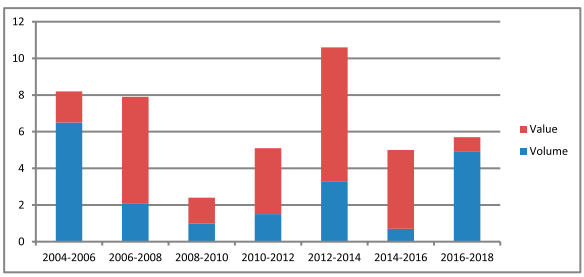

FIGURE 4 | Energy commodity futures turnover.

(1976), Peck (1976), and Telser (1981)). Research by Garbade and Silber (1983), Brorsen et al. (1984), and Yang et al. (2001) has concluded that a futures market dominates the price discovery process (2013). New information initially impacts futures prices, then spot prices. Even more than on the spot market, economic players may easily alter their holdings on the futures market when new information is received.

Price movement is an indicator of communication. The variation of underlying asset prices on the market is equal to the variance of information flow arriving in the absence of arbitrages (Ross, 1989). If not, it may provide a chance for arbitrage. Numerous investigations have backed up this idea. Similar to Johansen and causality tests, the amount of delays is computed in the same manner.

Over time, the market in China for young people has gained international importance and shown continuous improvement in the ability to efficiently sell goods. Despite the study results showing that Chinese energy futures markets remain susceptible to big price fluctuations, there are positive aspects of the research findings that suggest Chinese energy futures markets are still resilient. The authors are worried that speculative activity makes markets less capable of handling weird orders. The research articles are sparse: we found just two relevant documents. In each market, how prices rise and fall every day is examined.

The authors find that when volume rises, volatility rises as well; however, as open interest increases, volatility decreases. The findings imply that volatility is enhanced by speculative activity. Chen and Paulraj (2004) investigated the relationship between price movement and transaction volume for copper, aluminum, diesels, and wheat futures contracts, comparable to the work done by Moberly (2017).

The authors show that absolute returns and trading volume are positively correlated both contemporaneously and in the future, *via* Granger causality tests and correlation analysis. In addition, they find that absolute returns and trading volumes are closely connected. Only with copper does a significant connection exist between the two returns: the absolute return and the volume of trade (**Figure 4**).

Sustainable energy development incentives, preferred VAT, corporate tax, and corporation tax preference ratios are only a few of the existing tax rebate schemes in place in China. Tax cuts may encourage operational and maintenance investment by lowering investment costs and increasing cash flow *via* indirect fiscal spending, which in turn improves enterprises' cash flow. The basics of the endogenous financing of renewable energy corporations are cash flows, which indicate the availability of capitals that companies may freely manage.

As a result of tax reductions, sustainable energy companies are able to access external monetary resources, which in turn affects their spending intentions and reduces overall external financing limitations, thereby encouraging more lucrative renewable energy investment projects. Reducing borrowing costs and improving the investing advantages of renewable energy investments is a

result of higher tax ratio refunds that motivate renewable energy enterprises to engage in lucrative renewable energy projects and so promote renewables efficiency.

Sensitivity Analysis

A new property category for energy products prices volatility in the renewable energy industry has arisen during the last millennium. Clean energy and other asset types have been the subject of several research topics. However, academics have paid relatively little consideration to the question of how buyers with assets in clean energy efficiency might protect their bets. This study analyses whether commodities market volatility indexes may be utilized as hedging mechanisms against the downside risk of clean energy stock indexes in order to expand this sparse literature. This study's actual research takes into account the fluctuation indices for crude oil as well as heating oil, and three different clean energy stock indices. The DCC-GARCH model applied to the moment comparison groups is evaluated theoretically to determine the efficiency of hedge.

The following is a summary of the results of this inquiry. There is a negative correlation between the three fluctuation indices and the clean energy stock indices, which suggests that volatility indexes may be used to hedge clean energy stock indexes effectively. In practice, a rise in the implied volatility of crude oil or precious metals might counterbalance a decline in green power stock index returns (crude oil and heating oil).

This conclusion is supported by the asymmetrical DCC-GARCH model. Second, crude oil implied value is the strongest hedging instrument, following by crude oil and heating oil implied volume. It is also important to note that the correlations between pairs are time-dependent and hence not continuous. Commodity volatility and equities prices move in opposing directions, as seen by the negative analysis. Investing in both renewable energy assets and commodities fluctuation indices may help investors diversify their renewable energy stock price risk.

Discussion

First, we devised a method for calculating long and short-term price risks, which are crucial to long-term price risk. In order to accomplish this, monthly biodiesel, crude oil, and rapeseed prices in Germany were examined from 2003 to 2012. Only short-term variations in volatility have been studied thus far, with little attention paid to long-term trends. We utilize a Vector Error Correction Model (VECM) to filter out data to adjust for long-term price changes. A regression analysis is used to generate estimates of long-run and short-run price levels in the VECM. In the near term, a dynamic conditional correlation was employed to assess volatility and volatility linkages. Because it includes long-run dynamics that may be defined for the unconditional covariance matrix, the model utilizes non-parametric methods to provide a more flexible and accurate fitting approach than the (DCC) GARCH model.

The volatility measure determines the uncertainty in the result, which is one of the research's major flaws. When it comes to pricing, GARCH outperforms the competition and aids regime stability. Volatility regimes have no impact on price series when heteroskedasticity exists. The most serious problem with GARCH volatility is that it may lead to regime misclassification due to a failure to properly assess and characterize underlying variability. One last point to make about this study is that it overlooks the impact of trade. It would be interesting to see if trade or knowledge transfer dominates price transmission.

Even though the correlations between different products are low, and because products such as oil and grains tend to move together, it is conceivable that a single random component, affected by the effect of market connections, will be larger than anticipated. The fact that the energy sectors are so tightly connected is one explanation for the crossover. According to the findings, output shocks in the energy market would affect bioenergy feedstocks and, ultimately, food products. Since energy costs rise during a financial crisis, we learn that energy products earnings are passed on to farmers *via* an increase in the price of fuel. Return correlations may become more apparent as a result of shocks in one market, but these shocks may also ricochet to other markets, making return-volatility correlations persist for a long time.

CONCLUSION AND IMPLICATIONS

It mentions the relationship to products markets, such as the one previously brought up by Boako and Alagidede (2016). The findings of the study may help products index traders and fund managers get insights into their investments. Those who recently put money into products and now need to rebalance their portfolio without exposure to the volatile products markets may want to investigate African stock markets for diversification. The fact that African economies must increase products financialization supports the argument. The two most important alterations occurring in Europe are improved market dynamics and less debt; both of these support increasing investments. People must put in a huge effort to establish derivatives trading throughout the continent and prioritize introducing products exchanges and demutualizing local stock markets.

The implications of our research will be profound. The evidence suggests that rapeseed and biodiesel prices have an inextricable connection that will never leave them far apart. As a result, the rise and fall of prices will be in relation to how much deviation has occurred. The price of rapeseed and crude oil is not expected to be affected by the biodiesel market in the short term, but in the long run, it will be in direct response to changes in those other markets. Advocates must have the knowledge gained from this research in debates on how to lower increasing food prices. Biodiesel's volatility is more influenced by rapeseed's and crude oil's volatility, which is very mild. The link between rapeseed and crude oil volatility is increasing, although that does not hugely affect refining. Food security concerns have impacted markets everywhere, creating big changes that have upended the global economy.

A financial trader may stand in for a counterparty in a transaction if one has the expectation that prices will rise and enter into a futures contract. Volatility is what would impact the

value of the deals. People may avoid price fluctuation risks by controlling and receiving delivery of products through products futures markets. If a group of traders whose only interest is profit, or traders who are withdrawing their money from the market unexpectedly, suddenly affect the price volatility, it will go up significantly. To respond to Cheng and Xiong (2014) call for a scholar-led move beyond a simplistic bubble-like view of financialization, researchers are suggesting avoiding a "business as usual" distinction. Instead of concentrating on the potential benefits of financialization, additional study is needed to analyze the effect of it on three main products market functions: storage incentives, risk-sharing, and information discovery. This article covers the effect of investors on the market research for financial transactions. People like us have come before. Henderson et al. (2015) looked at the impact of financialization through products-linked notes (OTC) on information efficiency (CLNs). Issuances of CLNs may impact futures prices, since issuers of CLNs use their futures contracts to hedge their products price risk.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Green Investment for Sustainable Business Development: The Influence of Policy Instruments on Solar Technology Adoption

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Green investment in sustainable energy can overcome the dependence on fossil fuels worldwide. Renewable energy policies have become the key issue in both developing and developed countries; there is a need to focus on energy-related policies by regulatory authorities of these countries. The current study critically analyzes the performance of the existing renewable energy policy instruments to attract foreign direct investment (FDI) for solar energy development in Pakistan. We evaluate the moderating role of good governance and financial support between the nexus of renewable energy policy instruments and green FDI for the sustainable development of solar energy in the country. The present study used non-probability (purposive) sampling to collect data from 43 respondents (private investors, government officials, energy experts, and policymakers) by conveying an energy policy-related questionnaire survey. The response rate was 82.69%. The study has used partial least squares structural equation modeling to assess formulated hypotheses. The results indicate that the feed-in tariffs is the most effective policy instrument to attract FDI in the country's solar energy sector. The fiscal measures positively impact the green FDI for solar energy. The results further reveal that good governance and financial support positively and significantly moderate the nexus of renewable energy policy instruments and green FDI for solar energy. The main barriers have been identified over the whole solar energy spectrum. The study findings provide essential policy recommendations and a considerable manual for

Abbreviations: ARE, alternative energy; B2B, business to business; FDI, foreign direct investment; GFDI, green foreign direct investment; GW, Gigawatt; GWh, Gigawatt hour; IRENA, International Renewable Energy Agency; MW, Megawatt; MWh, Megawatt hour; NGO, non-government organization; RE, renewable energy; CAGR, compound annual growth rate; RPS, renewable portfolio standards; PV, photovoltaic; CO_2, carbon dioxide; SEM, structural equation modeling; PLS, partial least square; CR, composite reliability; AVC, average variance extracted; HTMT, heterotrait–monotrait; R&D, research and development; NEPRA, National Electric Power Regulatory Authority; AEDB, Alternative Energy Development Board; WAPDA, Water and Power Development Authority; CCO_2, consumption-based carbon emissions.

energy-related regulators, policymakers, and government institutions to adopt advanced renewable energy policy instruments to attract FDI in Pakistan.

Keywords: renewable energy, policy instruments, foreign direct investment, solar energy development, instrumental analysis, Pakistan

INTRODUCTION

Climate change and environmental problems have grabbed predominant attention in the past decade (Alola et al., 2021; Fareed et al., 2021; Adebayo et al., 2022a; Adebayo et al., 2022b) in political and economic discussions (Sun et al., 2019; Razzaq et al., 2021; Nuvvula et al., 2022; Wen et al., 2022). Modern life depends on reliable energy resources (Elavarasan et al., 2021; Wu et al., 2021; Abbasi et al., 2022; Ahmad et al., 2022; Miao et al., 2022); however, Pakistan faces a severe energy crisis, which has destructive impacts on the national economy (Tanveer et al., 2021). The energy shortage seriously affects people's professional and nonprofessional activities (Xiang et al., 2022). Like other developing countries, Pakistan requires massive energy to support its industry and large population (Ikram et al., 2019, 2020; Irfan et al., 2020). The electricity gap between demand and supply has been uncontrolled in the past few years, and this gap is pronounced in the summer season. The country faces the worst load shedding, that is, 10–12 h per day in urban areas and 16–18 h in rural areas (Chandio et al., 2021). In Pakistan, at least 51 million people, representing 27% of the total population, have no access to electricity, and half the population is deprived of clean cooking facilities (Irfan et al., 2021d). In Pakistan, by the end of May 2021, the total installed electricity generation capacity was 34,501 MW. It will increase to 53,315 MW by 2030.

Pakistan has a total potential of RE of about 167.7 GW, which is more than the country's total electricity demand (Ashraf and Iqbal, 2020). The National Electric Power Regulatory Authority (NEPRA) assesses a 66% share of thermal plants, and the remaining 34% is renewable energy encompassing solar, wind, hydroelectric, and bagasse-based technologies. The total energy production with power generation from 2019 to 2020 was 121,691 GWh (NEPRA, 2021a). The national energy mix by the end of May 2021, that is, the total energy production with power generation during the fiscal year 2019–2020, was 121,691 GWh, which includes 32% from hydroelectric plants, 57% from thermal plants, 8% from nuclear plants, and 3% from renewable energy (NEPRA, 2021b). The average electricity demand of the country is 17,000 MW; however, the authentic power generation is 14,000 in any season, and the government has to face a 3,000 MW average deficit that can rise up in summer to 5200 MW. The alternative renewable energy (ARE) policy has a clear direction that the country will achieve targets such as 20% of its electricity mix by 2025 and 30% by 2030 (GOP-Government of Pakistan, 2019). Conventional energy generation methods are required to replace the RE resources to achieve sustainable economic growth in Pakistan (Muhammad Kamran Khan et al., 2020). According to the Asian Development Bank, Pakistan's electricity consumption (kWh per capita) is 892. It is assumed to surge up with a CAGR of 5.8% by 2030 (SAARC, 2020). Currently, fossil fuels are the primary energy generation source of the country. The existing RE share is insufficient in the total energy mix due to unsuitable policies in the country.

The national economy is unable to afford a massive dependency on fossil fuels. Hence, the government needs to develop a new energy economy to adequately utilize RE sources such as solar, wind, or biogas to produce energy that can decrease the energy crisis. Pakistan has a vast solar power potential. Attractive policy incentives, a large market base, tropical geography, and research facilities can tackle the country's energy crises (Raina and Sinha, 2019). Currently, the government uses about 67% of the nonrenewable resources to meet the energy demand that is growing at 10% annually (Rafique and Rehman, 2017; Awan and Knight, 2020). Pakistan's RE sector only contributes 0.5% of the energy need, which is negligible (NEPRA, 2021a). By the end of 2020, the worldwide solar power installed capacity was 707 GW (IRENA, 2020). The SolarPower Europe agency explored that the worldwide solar capacity was 900 GW at the end of 2021 with a low scenario and 971 GW with a high system (Global solar council, 2021). Fortunately, the geographical location of Pakistan has plentiful potential for all types of renewable energy sources such as wind energy, solar energy, and bio-energy, which are nearly about 81 million tons/annum. The huge potential of biomass production to produce bio-energy by applying pyrolysis, gasification, transesterification, and combustion with different technologies can play a vital role in the economy of the country. The solar isolation is blessed with 5.5 Wh $m^{-2}d^{-1}$ in Pakistan, and the duration of annual mean sunshine is 8–10 hd^{-1} all over the country. The wind power potential is more than 20,000 MW, and the wind speed is 5–7 m s^{-1} in the coastal regions of Baluchistan and Sindh (Ghafoor et al., 2016). Pakistan has a 136.05–287.36 W/m^2 intensity of solar radiation on an average monthly, but the practical intensity of solar radiation is observed as more than 200 W/m^2. In Cherat, 76.49 W/m^2 is the lowest intensity of solar radiation, but in Gilgit, 339.25 W/m^2 is the highest solar radiation during December. In Pakistan, Southern Punjab, Sindh, and Baluchistan have an average solar radiation intensity from 1,500 W/m^2 to 2,750 Wm^2/day and 10 h a day throughout the year. Pakistan has the energy potential to produce 45–83 MW per month from 100 m^2 in the regions mentioned above (Adnan et al., 2012b). This study focuses on four RE policy instruments for attracting foreign direct investment (FDI), producing wind energy, solar energy, and bio-energy. The policy instruments, namely, renewable portfolio standard (RPS), feed-in tariff (FIT), fiscal measure (FM) or tax incentives, and emission trading schemes (ETS) are for attracting investors in Pakistan to develop the solar energy sector. An FIT is a process implemented to develop and encourage RE technology investments, especially solar energy. This policy typically offers

long-term contracts to producers (15–20 years) and deals with RE payments as advanced renewable tariffs for RE technologies. FIT is an extra incentive that funds the higher costs of renewables and lowers the generation costs for exporting generated energy and paying for any necessary upgrades to the electrical grid (United Nations ESCAP, 2012). The most powerful policy instrument can attract an FDI in RE projects. FM indicates a positive and significant impact on RE, especially in solar energy (Wall et al., 2019). RPS policies effectively promote wind energy generation in the United States (Menz and Vachon, 2006; del Río and Bleda, 2012). ETS aims to reduce carbon emissions through the market for tradable emission permits and sets a limit for carbon emission levels. In Europe and the United States, the other policy instruments indicate that interactions with ETS, energy production payment (EPP), and tendering (TEND) are negatively correlated with ETS depending on the abatement costs of various technologies and the admissible limit level of carbon emission. RE sources can be widespread expansion through policy instruments. E.T.S policy instruments are sometimes less efficient to EPP and TEND. Based on this evidence, we have selected these four policy instruments.

The literature has a gap concerning renewable energy policy instruments. The gap between power supply and demand has intensified due to large population. In Pakistan, the renewable energy sector has primarily inaccessible 1) renewable energy generation sources, 2) advanced directions of the energy sector, 3) arguments and renewable energy introduction, 4) complete energy sector evaluation, 5) energy mix, and 6) renewable energy sector's demand and supply gap. Even though the renewable energy sector has stayed under discussion by previous researchers (Kamran, 2018; Zafar et al., 2018; Irfan et al., 2019; Wang et al., 2020) and despite all research studies, some specific gaps have been identified, that is, 1) the proper utilization of the existing policy instruments and adopting new RE policy instruments to attract foreign investors by giving them tax incentives in RE investments; 2) assuming new instruments in the existing policy to attract foreign investors in the RE sector of Pakistan, principally solar energy; 3) the need to adopt advanced and effective policy instruments, such as modern FIT, tax incentives for solar energy, and RPS, which can globally attract FDI in the RE sector; and 4) green investment required by the country through the analysis of RE policy and policy instruments. In the current study, we have hypothesized on the RE policy instruments related to green FDI and have employed quantitative methods by PLS-SEM to test these hypotheses. This study is categorized into various sections. The next section discusses the research hypothesis development with a detailed literature review. The Research Methodology section provides the research design. The section Data Analysis and Results discusses testing of the hypotheses. The Discussions section discusses the findings of the study and its implications. Finally, the Conclusion section concludes the study and offers policy recommendations.

HYPOTHESIS DEVELOPMENT

Feed-in Tariff and Green Foreign Direct Investment

An FIT is a policy tool designed to promote renewable energy sources through investment. It promises to pay above the market price to small-scale solar energy or wind energy producers for what they deliver to the grid. Policies are to regulate and stabilize the price of RE (Mohsin et al., 2021). For producers, who produce clean energy, a remuneration will be provided to them through this mechanism. Based on the empirical finding in the literature, FIT is positively and significantly associated with attracting the total GFDI, such as in solar, wind, and the subsector of biomass (Wall et al., 2019). The present study evaluates the role of the RE policy instruments in attracting the GFDI in developing countries like Pakistan. FIT has a positive effect on the per-year capacity added by a country of per capita photovoltaic. The literature has underestimated the potential impact of FIT because a well-designed FIT has a much more significant effect than the average currently applied FIT effect. The well-designed FIT can be seven times greater than the total effect of the average FIT. Consistency significantly affects the effectiveness of the FIT when the tariff of FIT is low (Dijkgraaf et al., 2018). A previous research indicates that FIT has a positive and significant impact on numerous patent activities, especially in solar power (Böhringer et al., 2017). The RE production capacity is positively associated with economic growth. The policies of RE generation can increase the openness for foreign capital (Fotio et al., 2022). Pakistan has implemented an FIT policy to develop and promote the RE sector and eliminate the gap between demand and supply. With the inappropriate implementation of FIT policy in the RE sector, Pakistan's desired outcomes were not achieved. The FIT policy failed to create a healthy competition between the Government of Pakistan and its private and local investors in generating electricity (Pakistan, 2006).

Pakistan must revise its FIT policy to provide a stable political environment and financial incentives for solar energy development. RE policy instruments such as RPS, auctions, and FIT are the most effective instruments to reduce the RE project risk by increasing returns (Polzin et al., 2019). The FIT policy instrument is superior to attracting foreign investments in the solar energy sector due to its long-term agreements. Tax incentives and monetary subsidies positively promote the RE investment of the government of China, but the tax incentives have a more significant impact. The main supporting force is the subsidies to the development of micro-, small-, and medium-sized RE enterprises provided by the government of China (Yang et al., 2021). The empirical analysis shows that the FIT policy enhanced inventory turnover and profitability. The FIT policy is more favorable for private enterprises to increase inventory turnover. The solar photovoltaic industry of China has faced substantial effects on sustainable development by the FIT (Xia et al., 2020). The FIT policy tool has proved to reduce welfare loss (Ye et al., 2017). The policy of the region that could direct economic growth, globalization, and utilization of RE has indicated a significant effect on CCO_2 (Adebayo et al., 2022b). China had initiated these FIT policies in 2011 to promote the adoption of solar PV power (Polzin et al., 2019).

FIT policies aim to bring down the cost of RE by accelerating circulation and encouraging the learning of green technology. The government purchases green energy under the FIT mechanism and sets it above the market price. We suggest the first hypothesis based on the above arguments.

Hypothesis 1. (H1): There is a positive association between FIT and green foreign direct investment

Renewable Portfolio Standard and Green Foreign Direct Investment

The RPS mechanism presents electricity companies with RE resources or the production of a particular share of electricity. The impact of RPS on the overall electricity capacity is a one-third increase, remains significantly positive for wind and solar capacities, and shows the most considerable effect with consistent estimates. RPS is extremely negative or insignificant for geothermal and biomass power (Janak, 2021). The RPS policy instrument has a positive significance in reducing the investment risk and increasing the return for foreign investors when designed in a particular way in solar energy. However, unfortunately, RPS is not implemented in Pakistan (Zhang et al., 2017). RPS can attract GFDI in the RE sector worldwide (Wall et al., 2019). Pakistan requires policy instruments for achieving ambitious targets. For the green pathway, the government is required to provide financial, legislative, and solid political commitments and overcome the demand–supply gap through the electricity of thermal power generation (Aized et al., 2018). This policy instrument is primarily adopted in developed countries to attract foreign investors to invest in the RE sector. Still, it needs to be adopted in developing countries like Pakistan. RPS obligations have proved and empirically confirmed effective instruments through different studies to promote investment in RE. The study indicates that RPS obligations positively and significantly affect energy generation, especially in European countries' bioenergy developments (Bolkesjø et al., 2014). RPS policies effectively promote wind energy generation in the United States (Menz and Vachon, 2006; del Río and Bleda, 2012). RPS and RE policy reforms are effective sources in promoting China's solar and wind power generation (Dong and Shi, 2019). RPS policies can be more effective if combined with carbon pricing policies because these policies discourage conventional fossil sources from generating electricity. Several states in the United States have implemented these policies to encourage incentives, growth, and development of alternative energy technologies (Ogunrinde et al., 2018). The influence of RE use on CO_2 emissions is negative, while economic growth, urbanization, financial development, and agriculture have a positive impact on CO_2 (Adebayo et al., 2022a). As a result of the above discussion, we suggest the second hypothesis.

Hypothesis 2. (H2): There is a positive association between RPS and green foreign direct investment

Fiscal Measures and Green Foreign Direct Investment

The government pays one-time fully or partially capital-covering investment costs to promote investments in RE. FM supports the RE investments through tax reductions. For the green pathway, the government is required to provide financial, legislative, and solid political commitments and overcome the demand–supply gap through the electricity of thermal power generation (Aized et al., 2018). FM or tax incentives indicate a positive and significant impact on Pakistan's solar energy projects and alternative energy projects by foreign investors. Carbon taxation and emission trading are carbon pricing instruments that attract GFDI in Pakistan. With foreign investors using tax incentives, FM shows a positive and significant impact on RE projects, particularly solar energy (Muhammad Kamran Khan et al., 2020). Export diversification and RE can increase the load capacity factor with maintenance of environment quality (Fareed et al., 2021). Pakistan has faced policy issues in the RE sector, so private and foreign investors are confused about investing. Financial and tax incentives need to be provided to local and foreign investors to resolve these issues. Fiscal instruments promote environmental goals by being cost-effective and highlighting tax cases, which include other financial tools that achieve the ecological target by complementing each other (Kamran et al., 2020). The most common solutions to protect the environment from polluting industries and convert them into clean energy resources are the carbon taxation on solar, wind, and geothermal sectors (Hao et al., 2021; Iqbal et al., 2021; Zhang et al., 2021; Elavarasan et al., 2022; Fang et al., 2022; Irfan et al., 2022). Fiscal policy reforms in energy projects will increase return rates and tax revenues refunded to investors (Islam et al., 2021; Khan et al., 2021). RE projects for hometown investors will become more exciting and feasible, and that is why the supply of money investments will increase (Gielen et al., 2019; Alola et al., 2021). Based on these results, we propose the third hypothesis as follows.

Hypothesis 3. (H3): There is a positive association between FM and green foreign direct investment

Emission Trading Scheme and Green Foreign Direct Investment

The ETS scheme used for clean energy production, consumption, and regulation of the market emission trading, "cap and trade," or allowance trading is a market-based approach to controlling and reducing pollution and greenhouse gas emissions cost-effectively. The empirical evidence disclosed that ETS and REC positively impact investment in RE, especially in the wind sector (Wall et al., 2019). ETS has two primary components: a limit on pollution and tradable allowances equal to the limit (specific emissions quality). It allows the buying and selling of greenhouse emissions for cost reduction and financial incentives. The earlier study discussed that ETS has no statistical significance to attract FDI at the comprehensive level but is positively associated with solar energy development. The empirical evidence disclosed that ETS and REC positively impact investment in RE, especially in the wind sector (Lin and Jia, 2020). The solar energy sector of Pakistan is required to adopt ETS to attract investors for energy production at a low cost. ETS works as a spring of RE generation and its revenue as a subsidy. ETS is also used for government

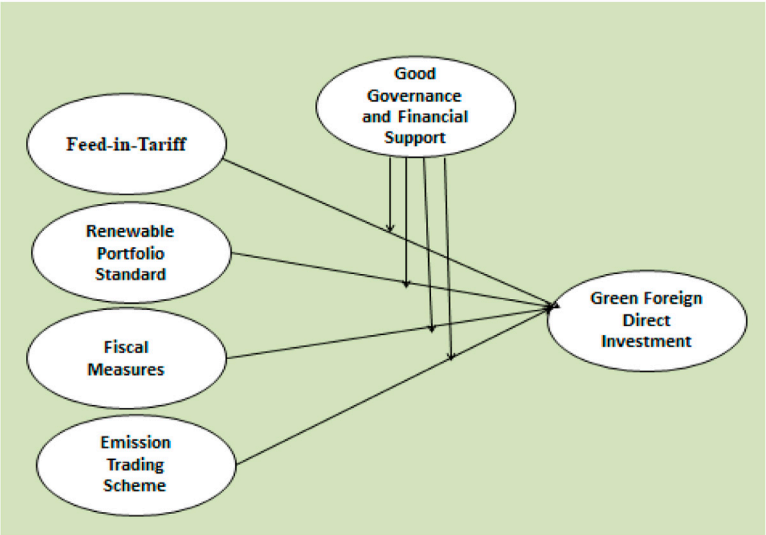

FIGURE 1 | Conceptual framework.

investment and consumption, which helps mitigate economic losses and caused investment by the government of China (McCrone et al., 2020). ETC aims to reduce carbon emissions through the market for tradable emission permits and sets a limit for carbon emission levels. In Europe and the United States, the other policy instruments indicate that interactions with ETS, energy production payment (EPP), and tendering (TEND) are negatively correlated with ETS, depending on the abatement costs of various technologies and limit levels of carbon emission. RE sources can be a widespread expansion through the ETS policy instrument (Keeley et al., 2018). Therefore, we suggest the fourth hypothesis based on the arguments above.

Hypothesis 4. (H4): There is a positive association between ETS and green foreign direct investment

The Moderating Role of Good Governance and Financial Support Between FIT and Green Foreign Direct Investment

Good governance is a process in which public institutions conduct public affairs and control public resources to promote rules and regulations. The complementarity between the indicators negatively affects CO_2 emissions of political and institutional governance and the financial sector. A good accompanied political and institutional governance can reduce carbon emissions with the development of the financial industry (Omri et al., 2021). The professional skills of deliverers should be strengthened and continuously maintained to improve their impact and output in renewable energy, and these are good governance guidelines (Majuri et al., 2020; Ahmad et al., 2021). Pakistan needs good governance in all sectors of life, but it is mainly required in the RE sector to eliminate the energy crisis by attracting GFDI. The green growth-related governance indicators with the highest maximum criterion value are 0.644 of the rule of law that plays a primary role in Pakistan. Good governance can play a vital role in achieving environmental sustainability objectives. All governance indicators can assist the legislators and organizations in understanding the importance of ISO 14001 certification to encourage sustainable practices in Pakistan (Abid et al., 2021). The country faces internal and external challenges, but good governance is a primary issue in political, sectarian, ethnic, and resource-based conflicts. Pakistan has focused on four types of indicators: the eradication of corruption, injustice, poverty alleviation, and nepotism; if it has taken them seriously, it will go a far way to ensure good governance in the country. Germany and Pakistan are already collaborating on renewable energy projects (Issue, 2019). Good governance supports the relationship of water availability with environmental degradation and renewable energy, but it has a weak relationship with FDI and environmental degradation (Ryota, 2018; Kousar et al., 2020). Moreover, we investigate the GFDI performance in the RE sector with the association of policy instruments. Finally, we have identified some specific research gaps after studying the literature in the proper utilization of the existing policy instruments and adopting new RE policy instruments to attract foreign investors by giving them tax incentives in RE investments. The policy gap by assuming new instruments to attract foreign investors in the RE sector of Pakistan, principally solar energy. There is a need to adopt advanced and effective policy instruments, including modern FIT, tax incentives for solar energy, and RPS, which can globally attract FDI in the RE sector. The country is requires green investment through the analysis of RE policy and policy instruments. The relationship of all parameters with green FDI is indicated in **Figure 1**. We suggest the fifth hypothesis, as a result, based on the above discussion.

Hypothesis 5. (H5): Moderating role of good governance and financial support between FIT and green foreign direct investment

Hypothesis 6. (H6): Moderating role of good governance and financial support between RPS and green foreign direct investment

Hypothesis 7. (H7): Moderating role of good governance and financial support between FM and green foreign direct investment

Hypothesis 8. (H8): Moderating role of good governance and financial support between ETS and green foreign direct investment

Research Methodology

The present study has applied a non-probability (purposive) sampling to collect data and attract GFDI in the solar energy sector for sustainable development. We have adopted four policy instruments for employing purposive sampling to present our sample from private investors, government officials, energy experts, and policymakers. We have surveyed from April to September (2021) to achieve this goal. Researchers faced stimulation of the delta variant that is the subtitle of coronavirus (COVID-19) when its pandemic was at the highest place in Pakistan (Irfan et al., 2021a; Irfan et al., 2021c); it was a very tough job to meet the related respondents. The researchers used social media apps to fulfill this purpose. Mobile applications, namely, WhatsApp and LinkedIn, were used to supply questionnaires. Purposive sampling is considered significant for assessing the entire population and theoretical generalization (Calder et al., 1981). The present research aims to evaluate RE policy instruments to attract GFDI and examine the moderating role of good governance and financial support among the nexus between RE policy instruments and GFDI in Pakistan. The respondents were selected using the following criteria: 1) respondents from different areas with diverse fields. The sector-wise quantity of the respondents was listed, such as private investors (11), government officials (7), energy experts (9), and policymakers (17); 2) relevant experience of the respondent was considered; and 3) the minimum limit for qualification of the respondent was a Bachelor's degree. The respondents were selected from diverse cultures and behaviors with a heterogeneous background according to the recruitment criteria. From this perspective, the selected sample size in this study is considered significant, and the findings are fruitful and considerable as these have been generated based on such a sample size with the heterogeneous attributes of the respondents.

Sample and Procedure

In this research, a total of 97 respondents were visited by different professionals, such as investors, RE experts, government officials, and policymakers. Among these, 89 agreed to participate in the study. After getting the respondents' consent, the researchers provided opened- and closed-hand questionnaires using a smartphone *via* WhatsApp and LinkedIn. Last, we received 82 filled questionnaires from the total respondents enrolled in this questionnaire survey. However, we had to discard four questionnaires due to non-relevant, inadequate, and unmatched responses. The calculated response rate was 87.64%. Finally, a total of 78 sample results showed valid responses from the different respondents for the analysis in this study. We had collected the personal data of the respondents through personal relations for investors using institutional websites for RE experts and policymakers and approached RE bodies for government officials. All findings are produced concerning the fair representation of the study sample. The respondents' demographic features (gender, age, experience and education) have heterogeneous backgrounds and respond properly in this research. The questionnaires have two sections: the first section covers the respondent's details, and the second section covers the questionnaires related to RE policy instruments to attract GFDI, sustainable solar energy development, and enhancement of energy supply and low-cost energy. **Table1** indicates the demographic profile of the respondents.

TABLE 1 | Demographic profile of the respondents.

Range	Features	Frequency	Percentage
Gender	Male	53	67.94
	Female	25	32.05
Education	Bachelor's	31	39.74
	Master's	28	35.89
	MS/M.Phil	19	24.35
Age, years	Less than 30	3	3.84
	31–40	21	26.92
	41–50	23	29.48
	51–60	18	23.07
	60 and above	13	16.66
Representative sector	Private investors	23	29.48
	Government officials	17	21.79
	Energy experts	22	28.20
	Policymakers	16	20.51
Work experience	1–3 years	11	14.10
	4–6 years	34	43.58
	7–10 years	17	21.79
	11–13 years	9	11.53
	>13 years	7	8.9

Instrument and Variables for the Measurement

The present study used scale items from the previous literature. The construct of feed-in tariff (FIT) policy instruments was measured with seven items (FIT). These seven items were taken and modified from a previous study (Cherrington et al., 2013). The eight items measuring the emission trading scheme (ETS) were adopted and modified from the study by Chen et al. (2017). Four items measuring the fiscal measures (FM) in the study were adopted and modified from the study by Onofrei et al. (2020). Six items measuring renewable portfolio standard (RPS) were adopted and modified from the study by Wall et al. (2019). Five items measuring good governance and financial support

TABLE 2 | Convergent validity analysis.

Constructs	Items	Loadings	Alpha	CR	AVC
Emission trading scheme	ETS1	0.921	0.978	0.981	0.865
	ETS2	0.942			
	ETS3	0.930			
	ETS4	0.931			
	ETS5	0.939			
	ETS6	0.926			
	ETS7	0.928			
	ETS8	0.924			
Feed-in tariff	FIT1	0.776	0.889	0.911	0.593
	FIT2	0.786			
	FIT3	0.778			
	FIT4	0.798			
	FIT5	0.715			
	FIT6	0.740			
	FIT7	0.792			
Fiscal measure	FM1	0.864	0.899	0.929	0.766
	FM2	0.876			
	FM3	0.882			
	FM4	0.880			
Green foreign direct investment	GFDI1	0.820	0.827	0.879	0.594
	GFDI2	0.818			
	GFDI3	0.843			
	GFDI4	0.651			
	GFDI5	0.703			
Good governance and financial support	GGFS1	0.982	0.965	0.974	0.884
	GGFS2	0.753			
	GGFS3	0.981			
	GGFS4	0.982			
	GGFS5	0.982			
Renewable portfolio standard	RPS1	0.836	0.893	0.919	0.655
	RPS2	0.853			
	RPS3	0.705			
	RPS4	0.760			
	RPS5	0.838			
	RPS6	0.853			

(GGFS), and all items of this moderator variable, had been adopted and modified from Ciborra and Navarra (2010) and Supriyati et al. (2019). Finally, five items measuring the GFDI had been taken as dependent variables and were adopted and modified from the studies of Hu et al. (2018) and Luo et al. (2021). We have employed a five-point Likert scale for assessing these items, specified as 1 for "strongly agree" and 5 for "strongly disagree."

Data Analysis and Results

The data were analyzed using this study's structural equation modeling approach (Ali et al., 2021; Irfan et al., 2021b). PLS-SEM is a component focus method used to analyze this study's rational dimensions (Urbach and Ahlemann, 2010). Many studies have used PLS-SEM due to its appropriateness and literature evidence (Hair et al., 2019; Ying et al., 2020); hence, the authors have employed it in this study. The use of structural equation modeling (SEM) in modern research can bring many benefits for fair analysis when compared to other approaches of traditional statistical analysis (Irfan and Ahmad, 2021; Irfan and Ahmad, 2022). PLS-SEM can assist our statistical analysis concerning the accuracy of results, efficiency in calculation, and convenience in findings (Henseler et al., 2015; Franziska et al., 2016). PLS-SEM is a second-generation technique, but it can solve issues regarding the first-generation analysis. PLS-SEM is a multivariate analysis instrument and is also helpful for analyzing abundant variables in the same model and time. PLS-SEM can simultaneously deal with multiple and complex relationships due to this unique quality; it is constantly widespread in business research (Chin and Newsted, 1999).

Management and social science research must adopt a suitable statistical tool because an improperly adopted analytical technique can explore inaccurate findings (Ramayah et al., 2010). PLS-SEM has two-stage analysis methods such as the measurement and structural assessment models, which provide results in two steps (Osborne, 2010). The measurement assessment model can provide the internal model assessment through validity and reliability of the currently used RE policy instruments in this study for attracting GFDI in Pakistan. The structural assessment model has many features, such as testing relationships and hypotheses or external model evaluation and risk assessment of the model for the RE policy instruments in this

TABLE 3 | Cross-loadings.

Items	ETS	FIT	FM	GFDI	GGFS	RPS
ETS1	**0.921**	–0.155	0.38	0.446	0.455	0.455
ETS2	**0.942**	–0.119	0.4	0.467	0.445	0.471
ETS3	**0.93**	–0.117	0.407	0.448	0.438	0.475
ETS4	**0.931**	–0.149	0.376	0.459	0.464	0.462
ETS5	**0.939**	–0.114	0.396	0.468	0.45	0.468
ETS6	**0.926**	–0.091	0.354	0.495	0.464	0.446
ETS7	**0.928**	–0.145	0.376	0.458	0.459	0.455
ETS8	**0.924**	–0.094	0.351	0.492	0.46	0.444
FIT1	–0.084	**0.776**	-0.121	-0.111	0.002	-0.091
FIT2	–0.096	**0.786**	-0.08	-0.075	0.026	-0.035
FIT3	–0.074	**0.778**	–0.089	–0.113	0.052	–0.003
FIT4	–0.158	**0.798**	–0.131	–0.14	–0.01	–0.061
FIT5	–0.069	**0.715**	–0.056	–0.028	0.088	0.042
FIT6	–0.05	**0.74**	–0.044	–0.076	0.044	–0.005
FIT7	–0.123	**0.792**	–0.048	–0.137	0.016	–0.07
FM1	0.35	–0.093	**0.864**	0.323	0.275	0.309
FM2	0.354	–0.096	**0.876**	0.328	0.326	0.389
FM3	0.345	–0.107	**0.882**	0.309	0.29	0.373
FM4	0.376	–0.097	**0.88**	0.368	0.347	0.403
GFDI1	0.398	–0.058	0.327	**0.82**	0.489	0.455
GFDI2	0.43	–0.142	0.359	**0.818**	0.437	0.46
GFDI3	0.404	–0.143	0.319	**0.843**	0.366	0.447
GFDI4	0.359	–0.099	0.185	**0.651**	0.264	0.305
GFDI5	0.338	–0.108	0.242	**0.703**	0.24	0.261
GGFS1	0.46	0.027	0.322	0.455	**0.982**	0.765
GGFS2	0.442	0.021	0.373	0.451	**0.753**	0.719
GGFS3	0.463	0.027	0.324	0.456	**0.981**	0.758
GGFS4	0.462	0.026	0.324	0.443	**0.982**	0.773
GGFS5	0.459	0.028	0.319	0.444	**0.982**	0.763
RPS1	0.386	–0.094	0.33	0.409	0.657	**0.836**
RPS2	0.451	–0.015	0.351	0.449	0.72	**0.853**
RPS3	0.315	–0.068	0.329	0.391	0.52	**0.705**
RPS4	0.398	0.006	0.348	0.38	0.642	**0.76**
RPS5	0.379	–0.097	0.332	0.406	0.657	**0.838**
RPS6	0.456	–0.015	0.36	0.45	0.709	**0.853**

study. We have employed PLS 3.0 software in the present study for the primary data analysis. PLS-SEM is used to scrutinize the links among the understudy model variables. Additionally, the structural equation modeling of covariance has a low statistical power than the partial least-square path modeling. PLS-SEM has preference and importance due to intercepting relationships while studying variables.

Furthermore, the variance-based SEM known as smart-PLS uses PLS, known as the path modeling approach to evaluate the nexus among the variables (Solangi et al., 2019). The main purpose of adopting the smart-PLS research hypotheses is to test and easily adopt a complex model in business research. There are two main approaches to smart-PLS: in this study, we have adopted both for research analysis, namely, the measurement assessment model and structural assessment model. The measurement assessment model can check the validity and reliability of constructs through discriminant and convergent validity. The convergent validity concerning correlation among all research items can be evaluated by using item loadings, composite reliability, and Cronbach's alpha. However, the cross-loading, heterotrait–monotrait ratio, and the Fornell–Larcker criterion were used to evaluate the correlation among the research variables associated with discriminant validity. Moreover, the measurement model could test and review the hypotheses using path analysis; the present study's analysis has been discussed in the Discussion section.

The present study has shown the links among the variables using path analysis. The current study results indicate that RE policy instruments such as feed-in tariff, renewable portfolio standard, fiscal measure, and emission trading schemes positively impact GFDI in Pakistan, and they accept H1, H3, and H4 and not H2. Moreover, the findings of this research also express that good governance and financial support significantly moderated the nexus between the feed-in tariff and fiscal measure and GFDI for solar energy in Pakistan; they accept H4 and H6. Finally, the findings of the measurement assessment model have indicated the nexus of convergent validity between the adopted RE policy instrument items in the current study. The table of convergent validity shows that the values of Alpha and CR are more significant than 0.70, while the values of AVE (Average Variance Extracted) and loading are greater than 0.50. The values of all items indicated convergent validity and high connection among all of the items. The study results also include correlation assessment among all items known as convergent validity. The figures of the convergent validity table highlighted that the CR values are more than 0.70, the AVE values are greater than 0.50, the Alpha values are more than 0.70, and the factor loadings have significant values more than 0.50. The above values indicated a valid convergent validity and high correlation among the items. **Table 2** shows all the results concerning convergent validity.

Measurement Assessment Model

In the current research study, the measurement assessment model is highly required to conduct validity and reliability tests of all constructs treated in the present model. The measurement assessment model approves the factor loadings of all items and confirms the validity and reliability of the constructs (Hair et al., 2019). The measurement assessment model is dependent on reliability tests such as internal consistency reliability and item reliability and on validity tests such as discriminant validity and convergent validity (Hair et al., 2011). The item reliability has been measured above the outer loading, and internal consistency reliability has been measured over CR. Finally, the convergent validity has been measured over AVE. The cross-loadings of all items are in a higher position along with the inception value of 0.50 (see **Table 2**. The present study analysis confirms that all values of the average factor loadings must be greater than 0.50, and each observation should contribute to the constructed variables. The suggested value of 0.50 should exceed the AVE. The measurements should be considered reliable when the value of CR of each standard surpasses the cutoff point of 0.70. The results of the selected RE policy instruments indicate that all the values of CR were between 0.879 (GFDI) and 0.981 (emission trading scheme). All values of AVE were between 0.593 (feed-in tariffs) and 0.884 (good governance and financial support). All the values of other additional loadings were between 0.50 and 0.982. The measurement assessment model indicates all the verified reliability and validity values in **Tables 2** and **3**. All items'

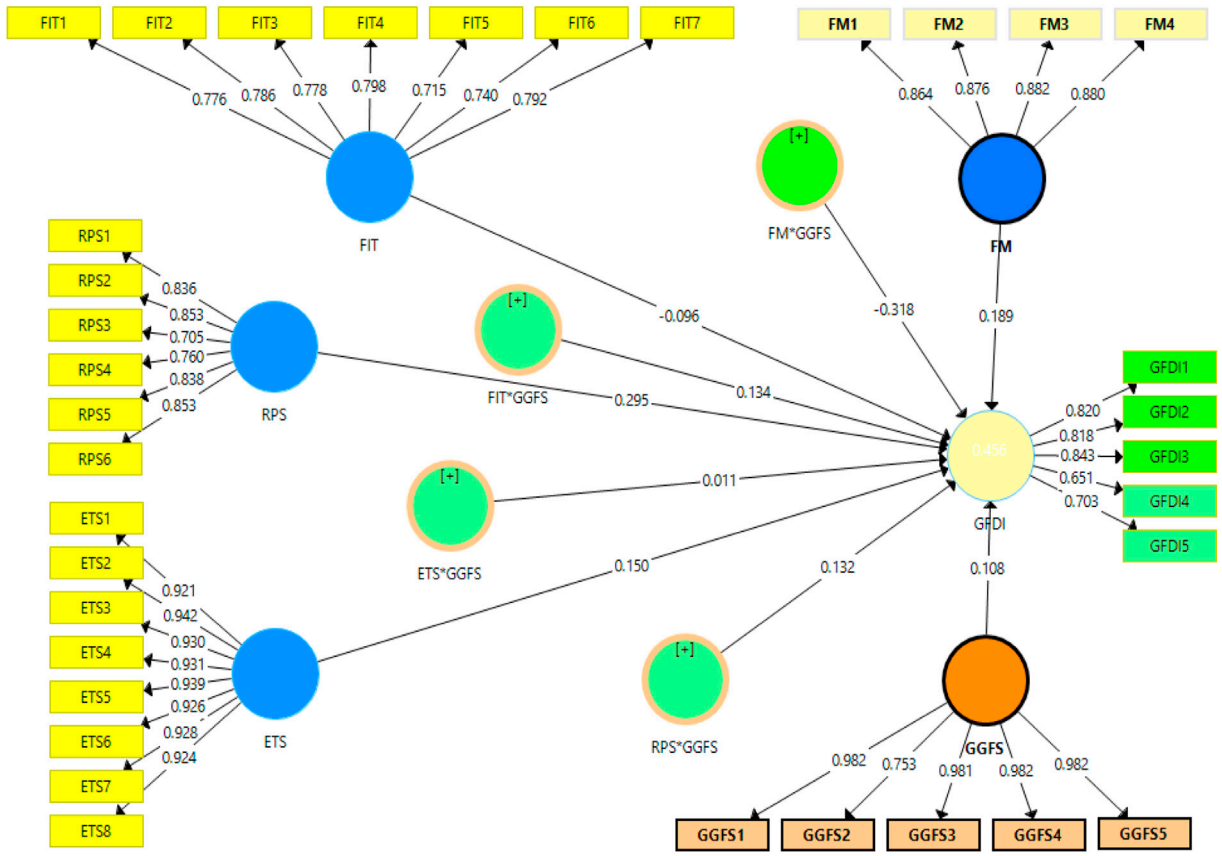

FIGURE 2 | Measurement assessment model.

convergent validity is valid in this model, and the real factor loading values are more significant than 0.50.

The assessment of correlation among the variables is presented in the research study findings as discriminant validity. There is a low correlation among the variables by indicating these values, and the discriminant validity is verified for the selected RE policy instruments in this study for solar energy. In **Table 3**, the bold values of all factors indicate a strong relationship, while it shows weak relationships with the other row-wise factors. These cross-loading table values are compared row-wise with other factors to check discriminant validity. Good governance and financial support values show strong discriminant validity in this study because row-wise, all values are greater than the other factors and so on. All bold values are greater than the values to their left and right in **Table 3**. **Figure 2** shows the measurement assessment model that displays the factor loadings of the variables.

Using the HTMT ratio of correlation measures the discriminant validity, which is more appropriate than the Fornell–Larcker criteria because many researchers criticize it (Akbar et al., 2019). If the value of discriminant validity is less than 0.85, it will be considered valid (Cohen, 1988) or 0.90 (Irfan et al., 2021b). **Table 4** shows that all values are lower than 0.90. The discriminant validity has also been indicated in the findings section nexus among the variables. The discriminant validity is tested through cross-loadings. The discriminant validity is valid and has a low connection among the variables. **Table 5** shows all highlighted values. The HTMT ratio is the latest approach used to test discriminant validity. The figures of the HTMT ratio indicate lower values than 0.90. These values are expressed as valid discriminant validity with less correlation among variables (see **Table 4**).

Structural Assessment Model

The structural assessment model and measurement assessment model are the two important steps of smart-PLS. We discuss here the structural assessment model which deals with checking the relationship between endogenous and exogenous variables. This model presents the various types of statistical values, namely, path coefficient (β values), coefficient of determination (R^2), predictive relevance (Q^2), effect size (f^2), and t-values. The criteria are provided by the PLS-SEM literature to estimate the level of significance of the path coefficient and evaluate the hypotheses. The bootstrapping process is applied by using 5,000 subsamples with a 5% significance level (one-tailed) to evaluate the significance level of the hypotheses (Hair et al., 2011). The results show that only H2 is not accepted, while the remaining hypotheses results are ETS ($\beta = 0.150$, $t = 2.229 > 1.64$, $p < 0.05$), ETS

TABLE 4 | Heterotrait–monotrait ratio.

Variables	ETS	FIT	FM	GFDI	GGFS
ETS					
FIT	0.130				
FM	0.435	0.118			
GFDI	0.557	0.152	0.430		
GGFS	0.503	0.050	0.38	0.522	
RPS	0.527	0.086	0.471	0.582	0.868

Notes: N = 43; ETS, emission trading scheme; FIT, feed-in tariff; FM, green foreign direct investment; GGFS, good governance and financial support; RPS, renewable portfolio standard.

relationship (moderator) ($\beta = 0.011$, $t = 0.227 > 1.64$, $p < 0.05$), feed-in tariff (FIT) ($\beta = -0.096$, $t = 1.983 > 1.64$, $p < 0.05$), FIT relationship (moderator) ($\beta = 0.134$, $t = 2.154 > 1.64$, $p < 0.05$), fiscal measure (FM) ($\beta = 0.189$, $t = 2.781 > 1.64$, $p < 0.05$), FM relationship (moderator) ($\beta = -0.318$, $t = 4.820 > 1.64$, $p < 0.05$), renewable portfolio standard (RPS) ($\beta = 0.295$, $t = 3.418 > 1.64$, $p < 0.05$), and RPS relationship (moderator) ($\beta = 0.132$, $t = 2.014 > 1.64$, $p < 0.05$) and have a significant and positive impact on GFDI.

The model has substantial explanatory power because the value of R^2 for ETS→GFDI is 0.439, which indicates that the RE policy instruments can attract GFDI for solar power projects. However, the efficiency and effectiveness of the model are not only measured with the value of R^2; this individual value cannot assist the model (Hair et al., 2021). Subsequently, in Q^2, the predictive relevance measurement of the structural assessment model is an appropriate method. The Q^2 value is considered more refined and sophisticated than 0 and is demonstrated with the latent exogenous standards by extreme predictive relevance (Akbar et al., 2019). In the present study, the Q^2 value is 0.251, indicating that the model has positive and significant predictive relevance and suggesting that the GFDI in solar energy increases through adopted RE policy instruments such as FIT. ETS, FM, and RPS in this study. There is a technical value of f^2. This includes 0.02, 0.15, and 0.35 and displays the three types of effects, that is, small, medium, and large, respectively (Cohen, 1988). Therefore, there are differentiations in the effect size of the f^2 values from medium to large (see **Table 5**). Many kinds of statistical techniques are used in this study, which are presented in **Table 5**. **Figure 3** shows the structural assessment model. In the present study, all variables indicate a positive and significant relationship in the model, and the t-values display more serious than 1.64, and the emission trading scheme does not have a positive and significant impact on the GFDI for solar energy. The results of the present study indicate that the values of the moderating variables have a significant relationship with the positive signs in the structural model to attract GFDI for solar energy in Pakistan.

DISCUSSIONS

Main Findings

The shortfalls of energy and severe load-shedding of electricity in Pakistan have compelled policymakers and local people to consider alternative energy sources. The RE policy instruments are positively associated with GFDI. The findings of this study indicate that the FIT policy instrument is the most suitable RE policy instrument to attract GFDI based on solar and wind energy. The results support a past study (Wall et al., 2019), which described that the FIT policy positively increases the renewable energy share. The FIT policy tool ensures the compensation for renewable energy producers on a specific period at a fixed rate. Furthermore, the results reveal that the selected policy instruments of RE in this study, such as RPS, FM, FIT, and ETS, have positively significant correlation with GFDI, especially in the solar energy sector in Pakistan. The results of this study are in line with past studies (Adnan et al., 2012a), which show that the FIT policy is an important policy instrument that can attract worldwide FDI in renewable energy. The study shows that FDI is the most effective policy instrument that can play a vital role to attract GFDI for the solar energy sector in Pakistan and internationally. These results align with the past study of Liao and Shi (2018), which shows that RE policy instruments such as FIT facilitate RE generation growth across international economies. The RPS policy has a positive role in attracting GFDI for solar energy, but it has not been implemented in Pakistan. The results of the current study match with those of a past study (Mirza et al., 2009), which shows that the RPS policy instrument has a positive significance in reducing the investment risk and increases returns for foreign investors when designed in a particular way in the solar energy sector. FM or tax incentives indicate a positive and significant impact on alternative energy projects, particularly in solar energy projects through foreign investors in Pakistan. The results of this study are the same as

TABLE 5 | Structural assessment model results (hypothesis testing).

Hypotheses	Relationship	Beta	SD	T-statistics	P values	Supported	R^2	Q^2	f^2
H1	ETS→GFDI	0.150	0.067	2.229	0.014	Yes	0.439	0.251	0.025
H2	ETS*GGFS→GFDI	0.011	0.048	0.227	0.41	No		0.243	0.021
H3	FIT→GFDI	–0.096	0.048	1.983	0.025	Yes			0.16
H4	FIT*GGFS→GFDI	0.134	0.062	2.154	0.017	Yes			0.030
H5	FM→GFDI	0.189	0.068	2.781	0.003	Yes			0.048
H6	FM*GGFS→GFDI	–0.318	0.066	4.820	0.000	Yes			0.135
H7	RPS→GFDI	0.295	0.086	3.418	0.000	Yes			0.043
H8	RPS*GGFS→GFDI	0.132	0.066	2.014	0.023	Yes	0.456		0.028

Notes: N = 43; ETS, emission trading scheme; FIT, feed-in tariff; FM, green foreign direct investment; GGFS, good governance and financial support; RPS, renewable portfolio standard.

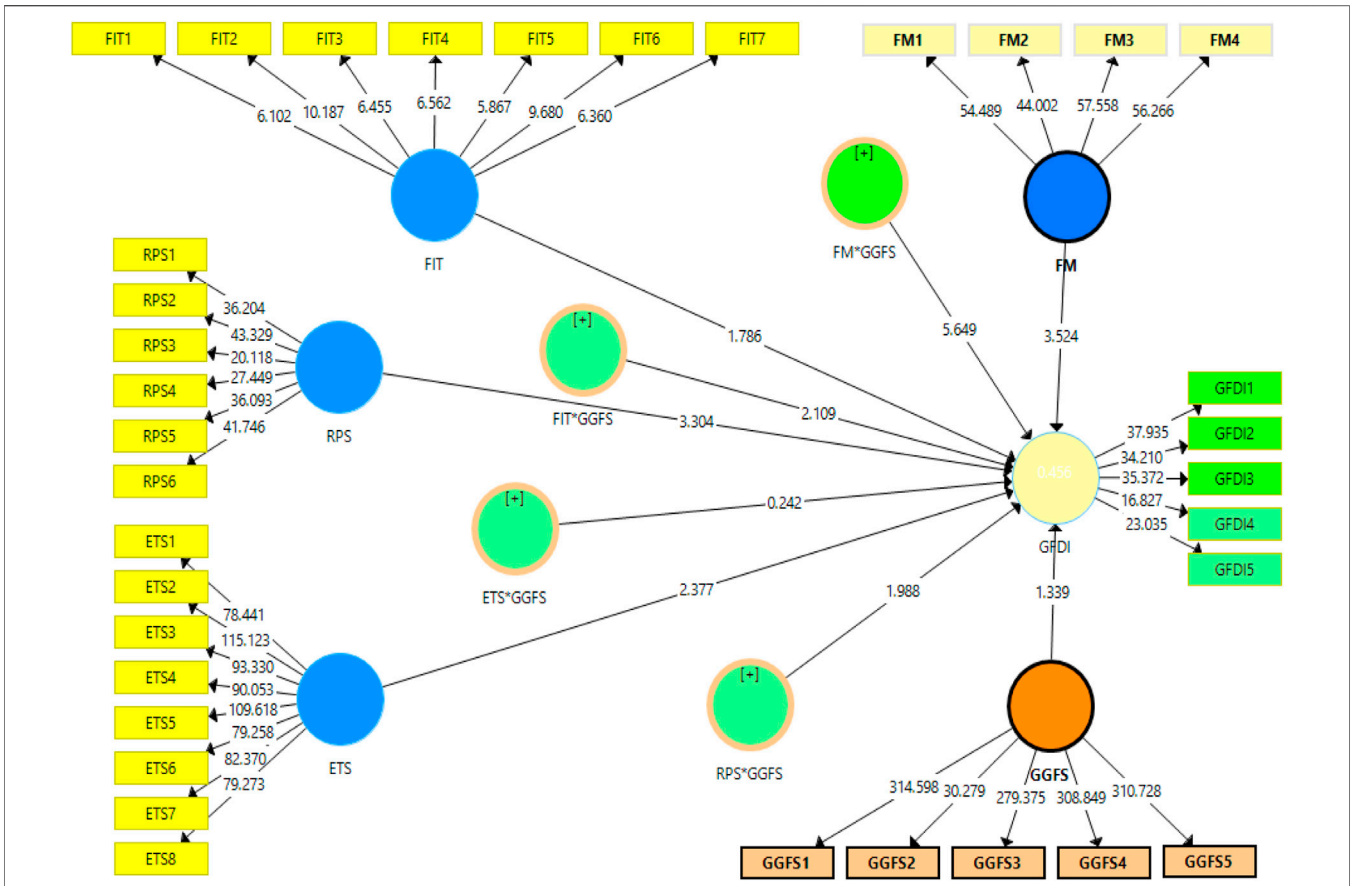

FIGURE 3 | Structural assessment models.

those of a past study (Mehran Idris Khan et al., 2020), which shows that FM has a positive and significant impact on solar energy projects to attract foreign investors using tax incentives. Conversely, public investments indicate a negative relationship with GFDI, and investors do not depend on government funds.

The vast potential of renewable energy sources is not appropriately utilized to overcome the energy shortage in Pakistan due to the lack of promoting policies and attractive infrastructure (Rafique et al., 2020). The present study will fill the policy gap by assuming advanced instruments in the existing policy to attract foreign investors in the solar energy sector. FIT, tax incentives, and RPS are the most powerful policy instruments which globally attract FDI in the RE sector. Many researchers found challenges in RE policy instruments. Still, no single researcher has described and evaluated the existing RE policy instruments over different factors to realize the best policy instrument to attract FDI for Pakistan. It is essential to conduct comprehensive research to bridge this research gap. This study will realize the most effective policy instrument to attract FDI for Pakistan. We have compared the efficacy of four RE policy instruments, namely, FIT, RPS, FM, and ETS, to attract investors for Pakistan to develop the solar energy sector. The research findings indicate that the FIT policy for solar energy is the best policy instrument due to many factors such as long-term (15–20 years) contracts, cost-based compensation, price certainty, and different prices for different RE sources. The model has substantial explanatory power because the value of R^2 for ETS→GFDI is 0.439, which indicates that the RE policy instruments can attract GFDI for solar power projects. Subsequently, in Q^2, the predictive relevance measurement of the structural assessment model is an appropriate method. In the present study, the Q^2 value is 0.251, which indicates that the model has a positive and significant predictive relevance and suggests that GFDI in solar energy increases through adopted RE policy instruments, such as FIT, ETS, FM, and RPS. In the present study, all variables indicate a positive and significant relationship in the model of this study, where the t-values display more serious than 1.64, and the emission trading scheme has no positive and significant impact on GFDI for the solar energy sector.

Major Challenges and the Future Prospects

The FIT policy is significant for Pakistan if it is adequately implemented. Additionally, we have discussed the significant barriers associated with solar energy in Pakistan through semi-structured interviews with private investors, government officials, energy experts, and policymakers. Finally, policy recommendations are proposed for the government institutions and policymakers to revise RE policy instruments and attract foreign and local investors to develop solar energy for Pakistan by eliminating these barriers.

Pakistan has a massive potential in RE, particularly in solar energy; however, the energy sector faces specific policy barriers, which are a significant hurdle to attracting FDI in Pakistan. Therefore, the country needs to remove and overcome these tremendous barriers to attract investments from international investors by employing alternative RE technologies effectively and efficiently. RE policies are not clearly defined for international and local private investors' participation in the RE sector, especially solar energy. Delay in allotments or clearance for international or local private investors discourages renewable projects. Buying power generators at a fixed-rate power purchase agreement structure is an insufficient incentive at fluctuating costs for RE sources for international or local power generators. The environmental structure is insufficient and weak for local and international investors. The existing FIT system is not justified and implemented adequately to attract FDI. It is mainly focused on the old and traditional power sources and lacks international-level policies for RE. Subsidies have a misbalance, and the central part of grants is provided to petroleum fuels compared to renewable sources to attract FDI. Unsatisfactory cooperation and coordination among the various policymaker ministries, agencies, institutes, and other stakeholders can delay the policy implementation. Delays in project allotments in renewable energy to international or local investors are significant reasons to demotivate international investors and limit the development, promotion, and commercialization in RE. The energy sector is deprived of overall coordination due to the absence of a central body. That is why R&D activities have repeated results. Being ineffective and lacking international-level legislation, the existing energy policies are non-effective to electricity prices and present regulations leading to misuse of subsidies and grants. The RE sector of Pakistan faces non-incorporation issues in the regulatory policy, and renewable technology penetration is limited due to the lack of awareness among policy regulators.

The RE sector faces technical barriers, high-risk perceptions, and resource assessment uncertainties to obtain financial loans. Small-scale projects of RE are facing the issue of financial resources and inappropriate lending facilities. International investors hesitate to invest in the RE sector of Pakistan due to many factors, including the short payback period and the high discount rate. However, these conditions can attract the investors, such as low capital costs of generation options, availability of a high efficiency, and shorter growth periods. The investment cost is a barrier due to the non-provision of financial support in the RE industry. Due to non-financial supports, incomplete working capital requirements, weak consumer service infrastructure, and operating and maintaining equipment, the RE policy always failed due to political issues in Pakistan. The fundamental and developing RE systems require an essential change, but the government machinery has failed in front of some politicians in making the necessary change. Pakistan faces operational RE issues, like weak plans, political influences, unrealistic targets, and small environmental R&D. The primary deficiency of the democratic government in Pakistan is prioritizing the policy of theory but a little bit to practice. Political parties misuse their power, and all subsidies of the renewable energy sector are used in another sector. The alternative energy sector is facing an absolute lack of politicians' will. Conflicts among political parties are the major issues for the energy sector in Pakistan. Political parties are working for the next election and not for the public issues in Pakistan. Political parties need to revise their democratic rule and consider energy shortage as a national issue.

The local technology of the solar system is not matched in Pakistan, and the country's federal government is not producing solar cells. The country depends on import-based technology for equipment and all essential parts. The solar radiation intensity is not checked with authentic solar maps. Large projects of solar energy depend on foreign sources to install and operate. Pakistan faces technical complications, such as inefficient knowledge of maintenance and operations, insufficient research and development initiatives, limited infrastructure availability, and unavailability of standards and energy storage. There is a lack of procedures and guidelines in RE technology with regard to performance, reliability, and durability. Due to these issues, RE cannot achieve large-scale commercialization goals. The primary technical issue is storage disturbing electricity grids due to the misbalance in demand and supply. Finally, the study has discussed conclusions in the last section. Hence, interested researchers must also identify the rest of the elements to adopting solar energy while considering the results of this study. We have selected RE policy instruments in developing countries such as Pakistan. Thus, the current study results are not equally valid for developed and underdeveloped countries. Therefore, the authors in the future must investigate the encouragements to attract investors for investment in solar energy in developed countries. Numerous factors and policy instruments other than those in this study affect GFDI. Upcoming researchers of this field are needed to analyze the other factors, except those that the current study has discussed. The single-source data collected in this study are not comprehensive for data collection. For the betterment of data validity, future scholars are encouraged to apply more data collecting sources while replicating the present research. Similarly, the research has evaluated the RE policy instruments currently working to attract FDI and those launched by the national policy in Pakistan being a developing economy. Consequently, the present study is equally valid for developed and developing nations. Therefore, authors in the future must identify the impact of other policy instruments on RE to attract FDI in both underdeveloped and developed countries.

CONCLUSION

Every country's progress and economic growth depend on a balanced energy supply in all sectors, even developed or developing economies. Developing economies such as Pakistan produce electricity through traditional fossil fuels to satisfy their county's need. Still, the demand and supply of energy have been unbalanced due to the increasing population and developments in heavy industries. Furthermore, the results reveal that the selected policy instruments of RE in this study, such as RPS, FM, FIT, and ETS, have been positively significant with GFDI, especially in the solar energy sector in Pakistan (see **Table 5**). The study has shown that FIT is the most effective policy instrument to play a vital role in attracting GFDI for solar energy in Pakistan and internationally. The RPS policy has a positive role in attracting GFDI for solar energy, but it has not been implemented in Pakistan. FM or tax incentives indicate a positive and significant impact on alternative energy projects, particularly in solar energy projects through foreign

investors in Pakistan. Conversely, public investments indicate a negative relationship with GFDI; investors do not depend on government funds. The study also indicates that carbon taxation and emission trading are carbon pricing instruments that significantly attract GFDI, but it is not implemented in Pakistan. Government funds or public investment for solar energy projects are not attracting private foreign investment due to the fact that they are not observed to be stable in the long run.

We investigated in this article that RE policy instruments are not fully facilitated to attract GFDI in the RE sector, especially in solar energy for Pakistan. Furthermore, Pakistan's RE policies and tax incentives are not satisfactory in attracting FDI or investors to invest in the solar power sector of Pakistan. We discovered that other factors also play a prominent role in attracting GFDI instead of policy instruments. The results indicate that the FIT policy attracts GFDI in RE for all categories, but it is not correctly implemented in Pakistan. RPS and FM (tax incentives) policies are also positive and significant in attracting FDI for solar energy in Pakistan and significantly impacting Pakistan's solar and other alternative energy projects through foreign investors. The present study results indicate that the values of moderating variables (good governance and financial support) have a significant relationship with the positive signs in the structural model to attract GFDI for solar energy in Pakistan. Carbon pricing instruments such as carbon taxation and emission trading attracted GFDI in Pakistan. The government's funds or investments for solar energy projects are not attracting private foreign investment due to the fact that they are not perceived as stable in the long run. Pakistan has an insufficient technical infrastructure and inappropriate financial resources to achieve the extension of RE technologies.

These results are applicable in other South Asian countries such as India, Sri Lanka, and Bangladesh by adopting FIT, RPS, FM, and CT policy instruments to attract FDI in the RE sector, especially solar energy. To develop and promote the RE sector, the government of Pakistan has advised specific policy recommendations to overcome the solar energy barriers discussed above (Aized et al., 2018; Irfan et al., 2019). Institutions relating to RE, the government, NGOs, and stakeholders should increase solar energy demand in Pakistan by working in a coherent and integrated way. These conclusions are drawn implicitly; there is a need to conduct further qualitative studies elsewhere in the scope of this research. However, we recommend this exciting and potential research direction for advanced research. Therefore, future authors must analyze the influences of other RE policy instruments such as CT to attract GFDI for solar power projects in other developing economies. Furthermore, with regard to data limitation, future studies are required to increase a large sample of the countries and country-level FDI data. The same survey can also be conducted in other Asian developing countries or states to check the availability of RE policy instruments for provincial governments to attract GFDI with low-carbon energy technologies.

Policy Recommendations

Moreover, the government should hire international and local professionals specializing in solar energy from developed nations. The country should increase RE resources by adopting RPS and FIT and reducing the heavy burden from fossil fuel power. These policy instruments can attract and motivate power producers to invest in solar energy. The country should establish sustainable and innovative financing programs to expand RE technologies. For the promotion and development of RE, the government should maintain an RE fund and lend based on attractive terms and conditions, especially for small investors. NEPRA and AEDB should consult to solve the limits of tariffs, define criteria for taxes, and purchase power from non-utility producers. Design specific power purchase mechanisms for wind and solar generation projects on a commercial scale.

The current study creates both empirical and theoretical implications. The significant literary research contributes to RE policy and CO_2 emission reduction literature globally. This study compacts with the influence of four policy instruments of RE, FIT, RPS, FM, and ETS, to attract GFDI in the country. This study adds to the literature by introducing the impact of these four RE policy instruments on GFDI for both developed and developing countries like Pakistan. The current study provides practical guidelines to the full institutional RE government bodies, ADEB and NEPRA, to adopt and adequately implement the existing policy instruments to attract local and foreign investors in the sustainable development of solar energy projects in Pakistan. The research study is of extreme importance to the RE policymakers and competent authorities of the energy sector such as Pakistan because the appropriate guideline of this research study improves the performance of the energy sector by attracting GFDI in solar energy projects. The best planning for RE policy instruments can attract local and foreign investors to improve the performance of solar energy projects by increasing GFDI in the country. Hence, RE policy instruments can attract a considerable investment and FDI in solar energy projects if the policy instruments are adequately defined by the competent government bodies and a government-owned statutory body: the WAPDA in Pakistan.

Additionally, Pakistan's RE policies and tax incentives are not satisfactory in attracting FDI or investors to invest in the solar power of Pakistan. We also discovered that other factors play a prominent role in attracting GFDI instead of policy instruments. For example, an FIT policy has been proved to attract GFDI in RE for all categories, but it is not correctly implemented in Pakistan.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This research study was conducted according to the Declaration of Helsinki guidelines and with the approval of the Institutional Review Board of the Superior University, Pakistan (protocol code 815-3 on 10-09-2021). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SA: Conceptualization, writing—original draft, formal analysis, data handling, variable construction and methodology, and

writing—review and editing. QY: supervision and funding acquisition. MI: Software, Methodology, Writing-review and editing, WA: Writing-review and editing. DWA: Writing-review and editing. AA-D: Writing-review and editing.

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Green Practices: A Solution for Environmental Deregulation and the Future of Energy Efficiency in the Post-COVID-19 Era

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The world has paid increasing attention to energy efficiency projects since the Paris agreement and UN climate summit. Recently, the COVID-19 pandemic accelerated the process of the green energy transition, which has attracted considerable attention from economists, environmentalists, and international organizations and has led to significant research in energy. This study addresses the importance of green energy practices in the post-COVID-19 era to deal with environmental deregulation using bibliometric analysis. Data were extracted from the Scopus database from 2020 to 2022. Results indicate that China gained a prominent place in publishing topic-related articles. However, Italy stands at the top position in total and average article citations. Sustainability is the most productive journal, followed by Energies and the Journal of Cleaner Production. Nazarbayev University and the University of Cambridge are the most contributing research institutes. In general, the cooperation of authors, institutes, and countries strengthens research; however, collaboration at the author level across the nation was lower than in others. The study highlights three research streams and four themes by systematically conducting a bibliometric coupling and co-occurrence network that anticipates and significantly segregates literature. Bibliometric coupling identifies three research streams of sustainable green business strategies, green infrastructure requirements, and green solutions and opportunities from COVID-19. Furthermore, the co-occurrence network proposes four main themes related to green innovation in the epidemic era, security and sustainable development goals with green practices, public health protection and green finance, and investment and risk management. The results provide insights into current research in the field of energy and will assist future work promoting environmentally friendly projects.

Keywords: green practices, environmental deregulation, energy efficiency, green economy, COVID-19

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1 INTRODUCTION

The world faces severe environmental challenges due to continuously changing lifestyles and business methods (Suki et al., 2022). The process of industrialization and economic appraisal results primarily from environmental deregulation that highlights the need to improve current production practices (Tamazian et al., 2009). In this scenario, energy efficiency is becoming

TABLE 1 | Descriptive for source information.

Description	Results
Documents	213
Sources (journals, books, etc.)	63
Keywords plus (ID)	1,636
Author's keywords (DE)	925
Period	2020–2022
Average citations per document	6.441
Authors	790
Author appearances	825
Authors of single-authored documents	24
Authors of multi-authored documents	766
Single-authored documents	25
Documents per author	0.27
Authors per document	3.71
Co-authors per documents	3.87
Collaboration index	4.07
Document types	
Articles	156
Book chapters	6
Conference papers	21
Conference reviews	2
Editorials	3
Reviews	22
Short surveys	3

TABLE 2 | Most productive authors.

Author	h_index	g_index	m_index	TC	NP	PY_start
Guney M	2	3	0.67	36	3	2020
Karaca F	2	3	0.67	36	3	2020
Tleuken A	2	3	0.67	36	3	2020
Tokazhanov G	2	3	0.67	36	3	2020
Turkyilmaz A	2	3	0.67	36	3	2020
D'Adamo I	2	2	0.67	81	2	2020
Jger Waldau A	2	2	1.00	20	2	2021
Ramakrishna S	2	2	1.00	13	2	2021
Shan Y	2	2	1.00	4	2	2021
Wang K	2	2	1.00	10	2	2021

important an important issue in addition to environmental pressure and increasing greenhouse gas emissions. The current energy system mainly relies on fossil fuels that are harmful to human health, society, and the environment (Mohideen et al., 2021). However, steady progress is being made globally in terms of the energy transition. Even though low carbon systems are eco-friendly, organizations still do not adopt them due to high adoption costs (D'Adamo et al., 2020; K. I.; Khan, et al., 2021a). The government and policymakers emphasized implementing an environment-friendly energy system such as photovoltaic electricity generation, hydrogen, and fuel cell technologies after the outbreak of COVID-19 (Tian et al., 2022). However, some environment-related regulations have been relaxed during COVID-19 to boost the economy (Gautam et al., 2022), meaning there are mixed opinions available in the literature regarding the adoption of the green energy processes during the pandemic.

Some scholars consider this pandemic an opportunity to re-think new environmental regulations through a paradigm shift from traditional green energy, economic recovery, and global solidarity through environmental sustainability (Okoh, 2021). Economic activities have slowed down due to pandemic activities on the one hand, while on the other hand, due to lockdown, the suspension of industrial activities reduces carbon emissions and positively impacts the environment (K. I. Khan et al., 2022). In developed economies, governments simultaneously supported clean energy projects and economic revival plans. However, in developing countries, governments have to cut down the cost to financially support economic recovery schemes (Gautam et al., 2022). Therefore, antagonism has been observed between positive and negative discourse. This might provide reasons for scholars and practitioners to raise questions about the future of energy transitions. Academic literature on the topic is overwhelming, making it difficult for scholars and practitioners to have a constructive overview of the relevant information. This study conducts a bibliometric analysis to discuss the importance of adopting green energy practices in the post-COVID-19 era to deal with environmental deregulation. This topic is relatively emerging in terms of academic research but has received increasing attention during the outbreak of the COVID-19 pandemic. This increase is driven by the fact that the focus of academics and practitioners had changed, adopting more eco-friendly practices that lead to a continuously growing publication rate on the topic and make it difficult to obtain a comprehensive overview. This bibliometric analysis helps to answer the following research questions: 1) what are the most relevant and impactful scientific actors (authors, sources, affiliations, and countries) in the literature; 2) what are the future trends and research streams of the topic?

2 METHODS

Bibliometrics analysis is an area of study that analyzes the bibliographic materials related to a particular topic of interest using quantitative methods (Nasir et al., 2021a). It is a widely used technique that summarizes the most significant contributions by key authors, journals, institutions, and countries in the field, which further highlights future areas of research for scholars (K. I. Khan, et al., 2021b). The current study conducted a bibliometric analysis on the importance of green energy practices adoption in the post-COVID-19 era to deal with environmental deregulation. Data were collected from the Scopus database for the post-COVID-19 era (1 January 2020, to 4 January 2022). We applied the query "TITLE-ABS-KEY (green AND (covid OR corona* OR sars* OR mers)) AND (LIMIT-TO (SUBJAREA, "ENER")) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2020))" and limited it to the subject area of energy. We adopted the strict criteria of document inclusion and added only relevant literature that falls under the scope of the study. We deleted the Errata, duplicates, documentaries, and documents not written in English. **Table 1** provides details about the documents used in the bibliometric analysis.

Table 1 shows that out of 213 documents, 156 are articles, 22 reviews, 21 conference papers, 6 book chapters, 3 editorials, 3

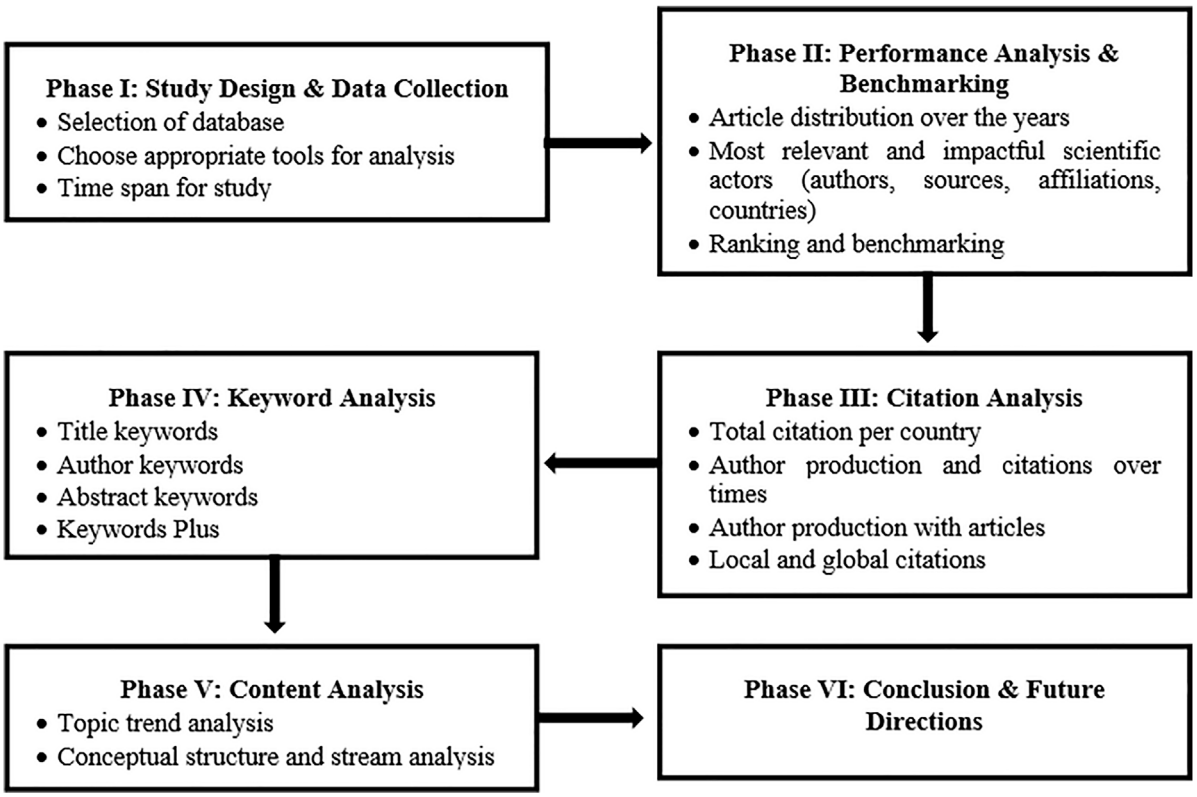

FIGURE 1 | Study phases.

short surveys, and 2 are conference reviews. The average citation per document is 6.44, while the collaboration index is 4.07. We used 'Biblioshiny' within R language for bibliometric analysis such as descriptive, keywords, co-occurrence, citations, and various factorial analyses, including content analysis. VOS viewer is used for mapping the interactions of the significant research actors. We applied Microsoft Excel tools to cross-check the analysis and produce editable figures and tables. Although the interpretation of the results is merely descriptive, the current study has added insight into the topic and future directions for further studies. **Figure 1** explains the detailed study design.

3 RESULTS

This section discusses the detailed study results based on the information extracted from the relevant and reliable sources. The study conducted performance and benchmarking analysis to explain article production in the post-COVID-19 period, most contributing actors (authors, sources, affiliations, and countries), ranking, and benchmarking. It then conducts citation analysis to highlight the total citations per country, author production, and citations over time. It also includes keyword analysis to specify the most frequently searched keywords included in the title, abstract, keywords, and keywords plus.

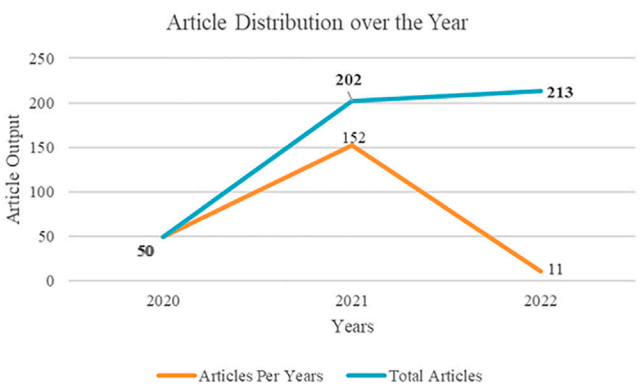

FIGURE 2 | Article distribution over the year.

3.1 Performance Analysis and Benchmarking

3.1.1 Article Distribution Over the Years

The number of articles published is considered an essential indicator to evaluate the development trend of research over the years. **Figure 2** presents the number of articles published during the post-COVID-19 era. Fifty articles were published in 2020, whereas in 2021, the number increased to 152. Until 2022, the date of query, a total of 213 peer-reviewed articles were

TABLE 3 | Most contributing sources.

Sources	Articles
Sustainability (Switzerland)	90
Energies	14
Journal of Cleaner Production	9
Applied Energy	6
E3S Web of Conferences	5
Energy Research and Social Science	5
International Journal of Biological Macromolecules	5
Sustainable Cities and Society	5
Environmental Footprints and Eco-Design of Products and Processes	4
ACS Sustainable Chemistry and Engineering	3

published. However, researchers expect this trend to grow over the years due to the increasing demand for green energy practice adoption (Suki et al., 2022).

3.1.2 Most Relevant Scientific Actors (Authors, Sources, Affiliations, and Countries)

The first five authors in the list of top-ranked authors have the same h, g, and m index values (h-index = 2; g-index = 3; and m-index = 0.67). Their total citations are TC = 36, and net production per article is NP = 3, and all articles were published in 2020 (see **Table 2**). These scholars highlighted the issue of designing comfortable and eco-friendly living spaces during the COVID-19 pandemic. Their findings stated that health and safety, comfort, and environment are the major aspects to consider in designing residential buildings (Tokazhanov et al., 2020). Later, Tokazhanov et al. (2021) sought an opinion from the stakeholders (academia, industry, and medical experts) on the previously identified indicators (health and safety, comfort, and environment) and found health and safety as the most crucial aspect among them. Their evaluating determinants for health and safety category are better building air quality, tenants' mental health, and prevention of virus propagation (Tokazhanov et al., 2021). Their study further elaborates that new designs must be equipped with modern touchless technology tools and a proper sanitation system, and greener spaces should be developed to improve mental health conditions without harming the environment (Tokazhanov et al., 2020). They also emphasized implementing green building certification systems (GBCSs) in the era of a virus outbreak (Tleuken et al., 2021). These authors also assessed the readiness of existing residential housing for the identified indicators of GBCSs dealing with pandemic-resilient requirements.

D'Adamo has the highest total citations (TC = 81) but ranked second among the most contributing authors in the field. D'Adamo and Rosa (2020) believe that climate change is the result of a deterioration in eco-friendly practices. There is a need to recognize the role of the green economy to avoid social and economic disasters in the future. The existing resources should be deployed efficiently to fulfill infrastructural needs and ensure energy efficiency. In this regard, D'Adamo et al. (2020), proposed integrating residential photovoltaic plants with the application of energy produced and self-consumed to develop a decentralized system. Photovoltaic energy is considered substantial for transitioning from fossil to a green society due to its cost reduction feature. The Italian Government also supported this policy, particularly during the COVID-19 period. They also provided an economic assessment of a 3 kW plant that creates an opportunity to handle environmental deregulations and generate a source of revenue for the consumer.

Jger Waldau stands at the third position with TC = 20; NP = 2. Jäger-Waldau (2021) is also a supporter of photovoltaic electricity generation and provided evidence of it becoming the fastest-growing power generation worldwide. This system is cost effective and plays an essential role in renewable electricity and energy efficiency (Kougias et al., 2021). Mohideen et al. (2021) emphasized the use of a low-carbon energy system that requires a transition from fossil fuel to hydrogen and fuel cell technologies. Fossil fuels contribute to massive greenhouse gas emissions, which affect human health, society, and the environment. However, the cost of a low-carbon energy system is high (Manganelli et al., 2021). The COVID-19 situation has prompted governments and policymakers to re-think future investment in eco-friendly energy areas in alignment with the sustainable development goals framework of the United Nations. Shan has focused on the air pollution caused by the transportation sector. COVID-19 affected the transportation sector, reducing energy demand CO_2 emission (Schulte-Fischedick et al., 2021). Cai et al. (2021) discussed improving customer satisfaction regarding tourist accommodation during the pandemic period.

Table 3 depicts the most contributing literature sources relevant to the topic. 'Sustainability' remains the most

TABLE 4 | Distribution of countries and institutional affiliations.

Countries	Frequency	Institutions	Affiliated countries	Articles
China	71	Nazarbayev University	Kazakhstan	8
Italy	62	University of Cambridge	UK	7
UK	36	National Research Centre	Egypt	5
United States	36	Sapienza University of Rome	Italy	5
Spain	31	Rey Juan Carlos University	Spain	4
India	24	University College London	UK	4
Poland	18	University of Groningen	The Netherlands	4
France	15	University of Padova	Italy	4
Australia	13	Cadi Ayyad University	Morocco	3
Germany	12	Financial University Under the Government of the Russian Federation	Russia	3

TABLE 5 | Top corresponding authors' countries.

Country	Articles	Freq	SCP	MCP	MCP ratio
China	27	0.14	15	12	0.44
Italy	24	0.13	17	7	0.29
India	11	0.06	10	1	0.09
Spain	10	0.05	5	5	0.50
UK	9	0.05	6	3	0.33
United States	9	0.05	6	3	0.33
Australia	6	0.03	3	3	0.50
Poland	6	0.03	5	1	0.17
Canada	4	0.02	4	0	0.00
Germany	4	0.02	2	2	0.50

impactful source in the field by publishing 90 research articles related to green energy, environmental concerns, renewable energy, energy and resources policy, sustainable development, carbon emission, climate change, and green practices. The second influential source of publication is 'Energies,' which publishes 14 articles and addresses the issue of climate scenarios, economic recovery, renewable energy, risk management, wind power, energy efficiency, energy policy, energy security, energy sustainability, renewable energy, energy consumption, transition pathways, and energy transition. The third most prominent source of publication is 'Journal of Cleaner Production' with nine publications. All the publications discussed the issue of energy efficiency in the context of COVID-19.

Table 4 shows the country-wise and institutional affiliation-wise distribution of publications. China is the most contributing country that published 71 articles on the topic. The second most influential country is Italy which published 62 articles. The UK and the United States stand at the third position with 36 publications. The other contributing countries in terms of publications are Spain (31), India (24), Poland (18), France (15), Australia (13), and Germany (12). **Table 4** also sheds light on the top-ranked institutions that published the relevant material related to green practices and energy efficiency. The Nazarbayev University of Kazakhstan has a top position in the list with eight publications. Two universities in the UK are included in the list: the University of Cambridge (8) and the University College London (4). In the third position, two universities are placed with five publications, whereas in the fourth position and fifth place, four and two universities stand with four and three publications, respectively.

Table 5 provides information about the corresponding authors' countries. China again stands at the top for the correspondence of 27 articles, having SCP = 15; MCP = 12; and MCP ratio = 0.44. Italy ranked at the top based on SCP (intra-country collaboration), while the MCP ratio (inter-country collaboration) of Spain, Australia, and Germany is the highest (0.50). The total articles published in Italy are 24; its MCP = 7; and the MCP ratio is 0.29. India is involved in the correspondence of 11 publications, whereas Canada and Germany have originated four articles.

TABLE 6 | Distribution of publication by Bradford law.

Sources	Rank	Freq	CumFreq	Zone
Sustainability (Switzerland)	1	90	90	Zone 1
Energies	2	14	104	Zone 2
Journal of Cleaner Production	3	9	113	Zone 2
Applied Energy	4	6	119	Zone 2
E3S Web of Conferences	5	5	124	Zone 2
Energy Research and Social Science	6	5	129	Zone 2
International Journal of Biological Macromolecules	7	5	134	Zone 2
Sustainable Cities and Society	8	5	139	Zone 2
Environmental Footprints and Eco-Design of Products and Processes	9	4	143	Zone 2
ACS Sustainable Chemistry and Engineering	10	3	146	Zone 3
Energy Economics	11	3	149	Zone 3
Energy Policy	12	3	152	Zone 3
Sustainable Production and Consumption	13	3	155	Zone 3
Energy	14	2	157	Zone 3
Environmental Research Letters	15	2	159	Zone 3
European Biomass Conference and Exhibition Proceedings	16	2	161	Zone 3
Frontiers in Energy Research	17	2	163	Zone 3
International Journal of Energy Research	18	2	165	Zone 3
Journal of Energy and Natural Resources Law	19	2	167	Zone 3
Proceedings - IEEE Congress on Cybermatics: 2020 IEEE International Conferences on Internet of Things, iThings 2020, IEEE Green Computing and Communications, GreenCom 2020, IEEE Cyber, Physical and Social Computing, CPSCom 2020 And IEEE Smart Data, SmartData 2020	20	2	169	Zone 3
Renewable and Sustainable Energy Reviews	21	2	171	Zone 3
12th International Symposium on Advanced Topics in Electrical Engineering, ATEE 2021	22	1	172	Zone 3
2020 IEEE 17th India Council International Conference, INDICON 2020	23	1	173	Zone 3
2020 IEEE International Smart Cities Conference, ISC2 2020	24	1	174	Zone 3
2020 IEEE Vehicle Power and Propulsion Conference, VPPC 2020 - Proceedings	25	1	175	Zone 3

TABLE 7 | Source impact.

Sources	h_index	g_index	m_index	TC	NP	PY_start
Sustainability (Switzerland)	12	20	4.00	588	90	2020
Journal of Cleaner Production	5	9	1.67	127	9	2020
Applied Energy	3	6	1.00	69	6	2020
Sustainable Cities and Society	3	4	1.50	19	5	2021
Energies	2	4	0.67	27	14	2020
Energy Research and Social Science	2	5	0.67	90	5	2020
International Journal of Biological Macromolecules	2	5	0.67	26	5	2020
Energy Policy	2	3	0.67	57	3	2020
Environmental Research Letters	2	2	0.67	128	2	2020
International Journal of Energy Research	2	2	1.00	6	2	2021

TABLE 8 | Total citation per country.

Country	Total citations	Average article citations
Italy	303	12.62
China	170	6.30
Norway	130	65.00
United Kingdom	119	13.22
United States	116	12.89
Japan	37	9.25
Greece	36	9.00
Kazakhstan	36	12.00
Poland	35	5.83
India	32	2.91

TABLE 9 | Author production and citations overtime.

Author	Year	Freq	TC	TCPY
D Adamo I	2020	2	81	27.0
Furuya K	2020	1	50	16.7
Luo S	2020	1	50	16.7
Guney M	2020	1	24	8.0
Karaca F	2020	1	24	8.0
Tleuken A	2020	1	24	8.0
Tokazhanov G	2020	1	24	8.0
Turkyilmaz A	2020	1	24	8.0
Jger Waldau A	2021	2	20	10.0
Guney M	2021	2	12	6.0

3.1.3 Ranking and Benchmarking

The total documents extracted from the Scopus database are 213, including articles (156), book chapters (6), conference papers (21), conference reviews (2), editorials (3), reviews (22), and short surveys (3). We assess the productivity of publications from one zone to another through Bradford's law (Nasir et al., 2021b). **Table 6** shows that only one journal 'Sustainability' falls in zone 1, which is considered Bradford's zone of the core journal, with 90 publications. Zone 2 contains eight documents that have a total of 53 citations. The most prominent sources in the second quantum are 'Energies' (14) and 'Journal of Cleaner Production' (9). The bottom zone included 16 sources with 32 citations and was cited at least one time from 2020 to 2022.

Table 7 presents the source impact to highlight the core journals related to the topic under study from the field of energies. The information about the top ten sources is arranged based on indexes (h, g, and m), total citation (TC), net production (NP), and publishing year (PY start). **Table 7** shows that the most prominent source of publication is 'Sustainability (Switzerland)' that has indexes (h-index = 12; g-index = 20; m-index = 4.00; TC = = 588; NP = 90) in 2020. 'Journal of Cleaner Production' stands at second position based on indexes (h-index = 5; g-index = 9; m-index = 1.67) in 2020. However, its total citations (TC = 127) are less than 'Environmental Research Letters' (TC = 128), and similar is the case with its net production (NP = 9), which is less than the net production (NP = 14) of the 'Energies'. The 'Applied Energy' ranked at third position with h-index = 3; g-index = 6; m-index = 1) in 2020. Its total citations are 69, and net production is 6.

3.2 Citation Analysis

Citation analysis represents the most cited documents for the country and authors' output during the sample period (Nasir et al., 2021a). It also differentiates the documents concerning local and global and local citation. **Table 8** provided the country-wise total citation (TC) and average article citation (AAC) information. Results show that Italy ranked at the top in terms of total citation (TC = 303), whereas Norway attained the top position in terms of average article citation (AAC = 65). China and Norway placed at the second and third positions (TC = 170; TC = 130), respectively, in terms of total citation. The United Kingdom got the second (AAC = 13.22) and the United States got the third position (AAC = 12.89) in the average article citation. India got at the last position in terms of total citations (TC = 32) and average article citations (AAC = 2.91).

Table 9 explains the author's production and citations over time. D' Adamo seems to be the most prominent researcher in the field of energy. He published two articles in 2020 with 81 citations, whereas his total citations per year are 27. Other than D' Adamo, Jger Waldau and Guney have also published two articles with TC = 20; TCPY = 10, and TC = 12; TCPY = 6, respectively, in 2021. Furuya and Luo ranked second with TC = 50; TCPY = 16.7, while all the remaining five authors (Guney, Karaca, Tleuken, Tleuken, and Turkyilmaz) have attained third place in 2020 with one publication (TC = 24; TCPY = 8).

Table 10 explains the local and global citations of the articles with their publication details. Venter et al. (2020)

TABLE 10 | Local and global citations.

Documents	DOI	Year	Local citations	Global citations
Venter et al. (2020), Environ Res Lett	10.1088/1748-9,326/ABB396	2020	7	125
Xie et al. (2020), Sustainability	10.3390/SU12176751	2020	5	50
Hosseini (2020), Energy Res Soc Sci	10.1016/J.ERSS. 2020.101,633	2020	4	86
Uchiyama and Kohsaka (2020), Sustainability	10.3390/SU12239842	2020	3	23
Lee and Woo (2020), Sustainability	10.3390/SU122310191	2020	2	18
Tleuken et al. (2021), Sustainability	10.3390/SU13020460	2021	2	10
Gosens and Jotzo, 2020, Environmental Innovation and Societal Transitions	10.1016/J.EIST. 2020.07.004	2020	1	14
Tokazhanov et al. (2020), Sustainability	10.3390/SU12208732	2020	1	24
Sui et al. (2020), Appl Energy	10.1016/J.APENERGY. 2020.115,966	2020	1	18
Barcaccia et al. (2020), Sustainability	10.3390/SU12145651	2020	1	23

have the highest local and global citations (LCs = 7; GCs = 125) for the article published in 2020. Their research focused on the impact of social distancing during the COVID-19 period on recreational activities. Results indicate that the outdoor recreational activities in green spaces have increased during the pandemic, indirectly mitigating the virus's spread. Furthermore, their findings highlight the importance of green open spaces in urban planning for attaining the goal of sustainable cities in the future (Venter et al., 2020). Xie et al. (2020) have the second-highest local citations, i.e., five, whereas their global citations are 50, the third-highest citations relevant to the topic. Their research discussed the impact of quarantine and social distancing policies on the mental and physical health of the people. The respondents emphasized the need for social interactions and fulfilled their needs by visiting the nearby parks, which helped them cope with the adverse health conditions. Their findings highlight the importance of urban parks, open recreational areas, and a green urban building environment in maintaining a healthy quality of life that fulfills the social interaction needs of the residents even during a pandemic period.

Table 10 reported that Hosseini (2020) has the second-highest global citations, i.e., 86, and the third-largest local citation, i.e., four, among the top ten articles. His study explained the direct and indirect consequences of COVID-19 on the transition of green and low-carbon energy adoption. He believed that the current pandemic scenario slows down the economic activities that ultimately impact the process of green energy adoption. The government should restructure its green policies and involve the private sector to effectively implement energy renewal and green efficiency strategies (Hosseini, 2020). Uchiyama and Kohsaka (2020) assessed the effect of socio-economic and environmental attributes of the urban residential areas on the access to a green environment. The visit to green places (parks, gardens, and agricultural lands) is essential for the planning, health, social justice, and equity of the residents, avoiding viruses in the future (Uchiyama and Kohsaka, 2020). Lee and Woo (2020) explored the impact of the newly announced post-COVID-19 energy-efficient strategy by the Korean Government to build a low-carbon and environment-friendly economic system. All these actions are taken to promote green energy practices that reduce the usage of traditional energy resources and help in the transition process.

Tleuken et al. (2021) emphasized the green building certification system in the post-pandemic era to facilitate a healthy environment in the urban areas. Gosens and Jotzo (2020) discussed the Chinese new deal policy anticipated to support the green energy transition in the post-COVID-19 era. However, the policy has emphasized more investment in fossil fuel industries than in renewable energy projects. They believe that COVID-19 may reduce the Chinese ambition to implement green energy plans, so they must reconsider it to avoid future disasters (Gosens and Jotzo, 2020). Tokazhanov et al. (2020) emphasized the comfortable and eco-friendly residential buildings to promote a healthy environment during viral disease spread. Sui et al. (2020) provided evidence about understanding the emission patterns of buses and cars during a pandemic period and emphasized taking better investment decisions to promote an environment-friendly public transport system in the future. Barcaccia et al. (2020) discussed the impact of COVID-19 on food and agri-based businesses and emphasized research and development activities to promote these businesses.

3.3 Keyword Analysis

Keyword analysis reports the most repeated and frequently used essential concepts in the main body of an article from a specific field during the period under study. Table 11 highlights the top ten most significant concepts, words, and phrases used in the green energy literature during the post-COVID-19 era in the field of energy. These keywords are primarily used in the titles, abstracts, authors' keywords, and keyword plus. Their comparison analysis confirms the existence of similarities in the most employed words in the body of the article. For example, 'Covid 19,' 'Green,' 'Energy,' 'Sustainability,' 'Development,' 'Pandemic,' and 'Sustainable' are the frequently used words in all categories of keyword analysis.

Another important point presented in **Table 11** is that the concept of green energy is not limited to the field of energy but is also related to the diversified fields of social sciences such as economics, finance, and environmental sciences. For example, keywords such as 'Investments' and 'Green Bonds' are more relevant to the field of finance. At the same time, 'Development,' 'Urban,' 'Economic,' 'Sustainability,' and 'European Union' are more related to the discipline of economics. On the other hand, the keywords 'Climate Change,' 'Renewable Energy,'

TABLE 11 | Distribution of publications on green energy efficiency by keyword.

Title		Abstract	
Words	**Occurrences**	**Words**	**Occurrences**
Covid	80	Green	377
Green	80	Energy	311
Energy	35	Covid	300
Pandemic	30	Pandemic	204
Sustainable	30	Sustainable	165
Urban	23	Development	146
Sustainability	18	Authors	144
Review	17	Study	129
Case	16	Economic	126
Analysis	15	Sustainability	120

Author keyword		Keyword Plus	
Words	**Occurrences**	**Words**	**Occurrences**
Covid 19	59	Covid 19	61
Sustainability	24	Sustainability	42
Sustainable Development	15	Sustainable Development	33
Renewable Energy	11	Viral Disease	20
Covid 19 Pandemic	10	Coronavirus	18
Climate Change	9	Investments	18
Pandemic	6	Climate Change	17
Resilience	6	Epidemic	17
Energy Efficiency	5	European Union	12
Green Bonds	5	Greenspace	12

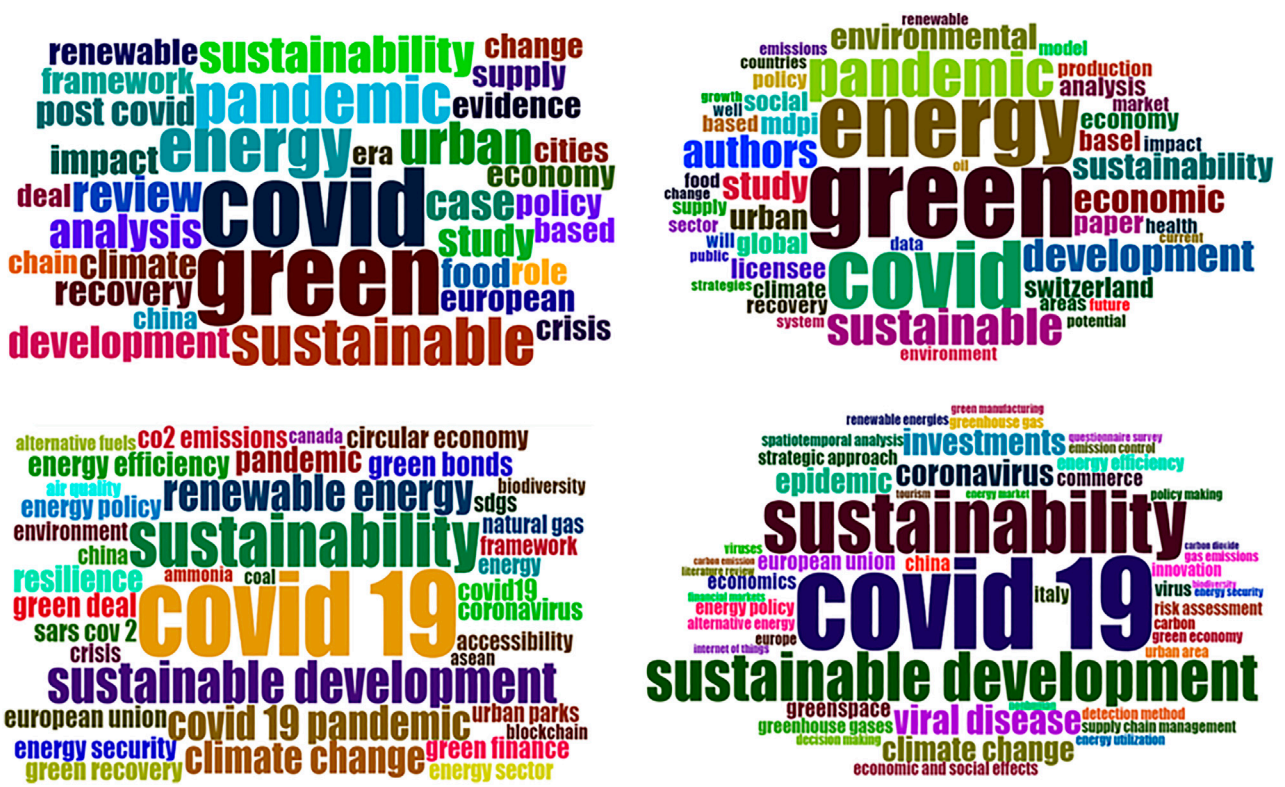

FIGURE 3 | Abstract keywords, title keywords, author keywords, and keywords plus.

TABLE 12 | Bibliometric coupling.

Label	Cluster	Weights		
		Links	Total link strength	Citations
Trivellas et al. (2020)	1	5	6	10
Khan M S et al. (2020)	1	6	6	9
Yousaf et al. (2021)	1	3	4	5
Khan M M et al. (2020)	1	3	4	21
Alaimo et al. (2020)	1	3	4	36
Arribas-Ibar et al. (2021)	1	3	4	11
Jian et al. (2020)	1	3	3	11
Su et al. (2021)	1	1	3	5
Bayulken et al. (2021)	1	2	3	8
Lv et al. (2020)	1	4	3	9
Alvarez-Risco et al. (2021)	1	2	2	5
Amicarelli et al. (2021)	1	1	2	11
Pulighe and Lupia (2020)	1	1	2	54
Han et al. (2021)	1	2	2	5
Chi Ffoleau and Dourian (2020)	1	1	1	14
G. Barcaccia et al. (2020)	1	1	1	23
Tokazhanov et al. (2020)	2	7	28.9999	24
Tleuken et al. (2021)	2	7	28.9999	10
Herman and Drozda (2021)	2	8	6.9999	7
Cai et al. (2021)	2	6	6	7
Uchiyama and Kohsaka (2020)	2	3	4	23
Barbarossa (2020)	2	7	3.9999	25
Hodor et al. (2021)	2	5	3.9999	6
Marek (2021)	2	3	3	14
Lidskog et al. (2020)	2	3	3	9
Cooke, (2021)	2	2	2	5
Lee and Woo (2020)	2	2	1	18
Xie et al. (2020)	2	1	1	50
Heo et al. (2020)	2	1	1	14
Bărbulescu et al. (2021)	2	2	1	5
Gutiérrez et al. (2021)	2	1	1	5
Oncioiu et al. (2021)	3	4	10	5
Gusheva and De Gooyert (2021)	3	2	8	5
Yanguas Parra et al. (2021)	3	4	5	5
Nikas et al. (2021)	3	7	4.9999	21
Strielkowski et al. (2021)	3	5	2.9999	12
Gosens and Jotzo (2020)	3	2	2	14
Kougias et al. (2021)	3	2	2	8
Frank and Wali (2021)	3	4	1.9999	5
Mohideen et al. (2021)	3	4	1.9999	9
Ali Shah et al. (2021)	3	1	1	29
(Sui et al., 2020)	3	2	1	18
Chernysh and Roubík (2020)	3	1	1	7
Jäger-Waldau (2021)	3	1	1	12
Gürdür Broo et al. (2021)	3	1	1	7
Chehade and Dincer (2021)	3	3	0.9999	10

'Greenspace,' and 'Energy Efficiency' are mainly discussed in the environmental sciences field.

Some generic terms are used in the title and abstract keywords that represent the research terminologies such as 'Analysis,' 'Study,' 'Review,' and 'Case.' **Figures 3.1–3.4** depict the most important words used in the article. These words/concepts/phrases were identified through word cloud analysis, where their size reflects the importance of the word. In **Figure 3.1**, the five most essential words are COVID-19, green, energy, sustainability, and development. In **Figure 3.2**, the most popular phrases are energy, green, sustainable, COVID, and development. **Figure 3.3** includes COVID-19, sustainable development, renewable energy, and climate change, whereas investment, COVID-19, sustainability, viral disease, and climate change are the most prominent words found in **Figure 3.4**. Interestingly, China is the major country found in the title and author keywords, while Switzerland has existed in abstract keywords and Italy is identified in keyword plus analysis.

4 CONCEPTUAL FRAMEWORK

In addition to the main influential aspects, the conceptual framework to identify core themes and research streams in the

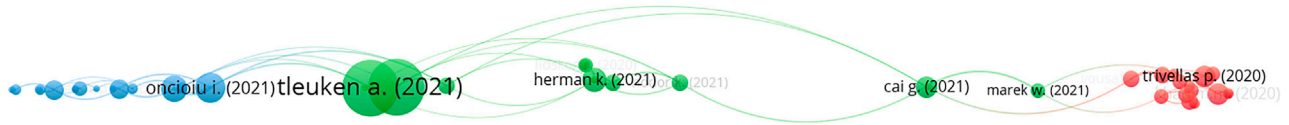

FIGURE 4 | Bibliometric coupling.

TABLE 13 | Co-occurrence network and recommended themes.

Keywords	Cluster	Suggested theme
covid-19, sustainability, coronavirus, viral disease, epidemic, innovation, policymaking, green economy, strategic approach, supply chain management, carbon emission, environmental policy, research, and development	1	Sustainable, innovative, and strategic green policies in the epidemic era
investments, energy policy, renewable energy, economics, alternative energy, gas emissions, carbon, energy security, economic and social effects, energy efficiency, costs, energy market, sustainable development goal, energy, renewable energy resources, fossil fuels, recovery, and energy management	2	Energy security and sustainable development goals for social and economic development
sustainable development, climate change, European Union, greenhouse gases, greenhouse gas, emission control, environmental impact, public health, biodiversity, tourism, viruses, European commission, green deal, and planning	3	Green practices and public health protection
risk assessment, commerce, investment, green bond, financial markets, and green bonds	4	Green finance, investment, and risk management

relevant topic may provide critical implications and future research directions. Therefore, we adopt the strategy (Khan et al., 2021a) that uses the bibliometric coupling and co-occurrence network to identify key research streams and themes.

4.1 Bibliometric Coupling

Bibliometric coupling occurs when two articles cite the same references (Kessler, 1963). Figure 8 shows the bibliometric coupling of the green energy practices literature. We used a VOS viewer to conduct analysis and found three clusters separated by blue, green, and red colors. The bubble size is dependent on the relative link strength of the document label with other labels. Figure 8 highlights three clusters representing contemporary themes, and details of these themes are provided in **Table 12**.

Figure 4 shows three main clusters of green practices, energy efficiency, and environmental deregulations. These clusters represent various research streams based on bibliometric coupling among articles, explained in **Table 12**. The strength of a relationship is measured by links, total link strength, and citations. The main research stream of cluster 1 (red) is the sustainable green business, supply chain, and food security strategies in a pandemic. The main findings of the cluster are sustainable supply chain management and food safety in COVID-19 (Trivellas et al., 2020; Su et al., 2021; Chi Ffoleau and Dourian, 2020). Furthermore, the research stream provided details about food security (Khan M M et al., 2020; Pulighe and Lupia, 2020) and innovative sustainable ecosystems (Arribas-Ibar et al., 2021). Cluster 2 (green) possesses highly linked articles, and the main research stream is defined as the post-COVID-19 environment and strategies for green infrastructure management. The cluster explains the green infrastructure dynamics in social distancing during COVID-19 (Herman and Drozda, 2021), green practices and infrastructural requirements during pandemic (Tokazhanov et al., 2020; Tleuken et al., 2021), and innovative policies for sustainable transitions during COVID-19 (Lee and Woo, 2020).

The third cluster is constructed on fifteen research articles. The main research stream is about green solutions, recovery, and opportunities from the COVID-19 pandemic. The highly linked article is written by Oncioiu et al. (2021), who saw COVID-19 not as a threat but as an opportunity for sustainability and the development of green practices. Furthermore, cluster 3 provides relevant literature regarding green recovery strategy during pandemics (Gusheva and De Gooyert, 2021; Ali Shah et al., 2021), efficient management of energy consumption (Strielkowski et al., 2021), and environmental protection (Frank and Wali, 2021; Chernysh and Roubík, 2020).

4.2 Co-Occurrence Network

A co-occurrence network provides rigorous analysis to find thematic patterns in the literature using the link strength of the most significant keywords. The study uses a VOS viewer to conduct the co-occurrence analysis and provided details of keywords in **Table 13** with identified cluster and recommended theme. The co-occurrence network is divided into four dynamic clusters (red, green, blue, and yellow) with a significant underlying study theme, presented in **Figure 5**.

The keyword segregation, cluster information, and recommended themes related to **Figure 5** are provided in **Table 13**. The red cluster in **Figure 5** represents the theme of sustainable, innovative, and strategic green policy in the epidemic era. The stated theme provides a detailed explanation of green strategies and environmental quality (Magazzino et al., 2021), sustainable and innovative ecosystem (Arribas-Ibar et al., 2021),

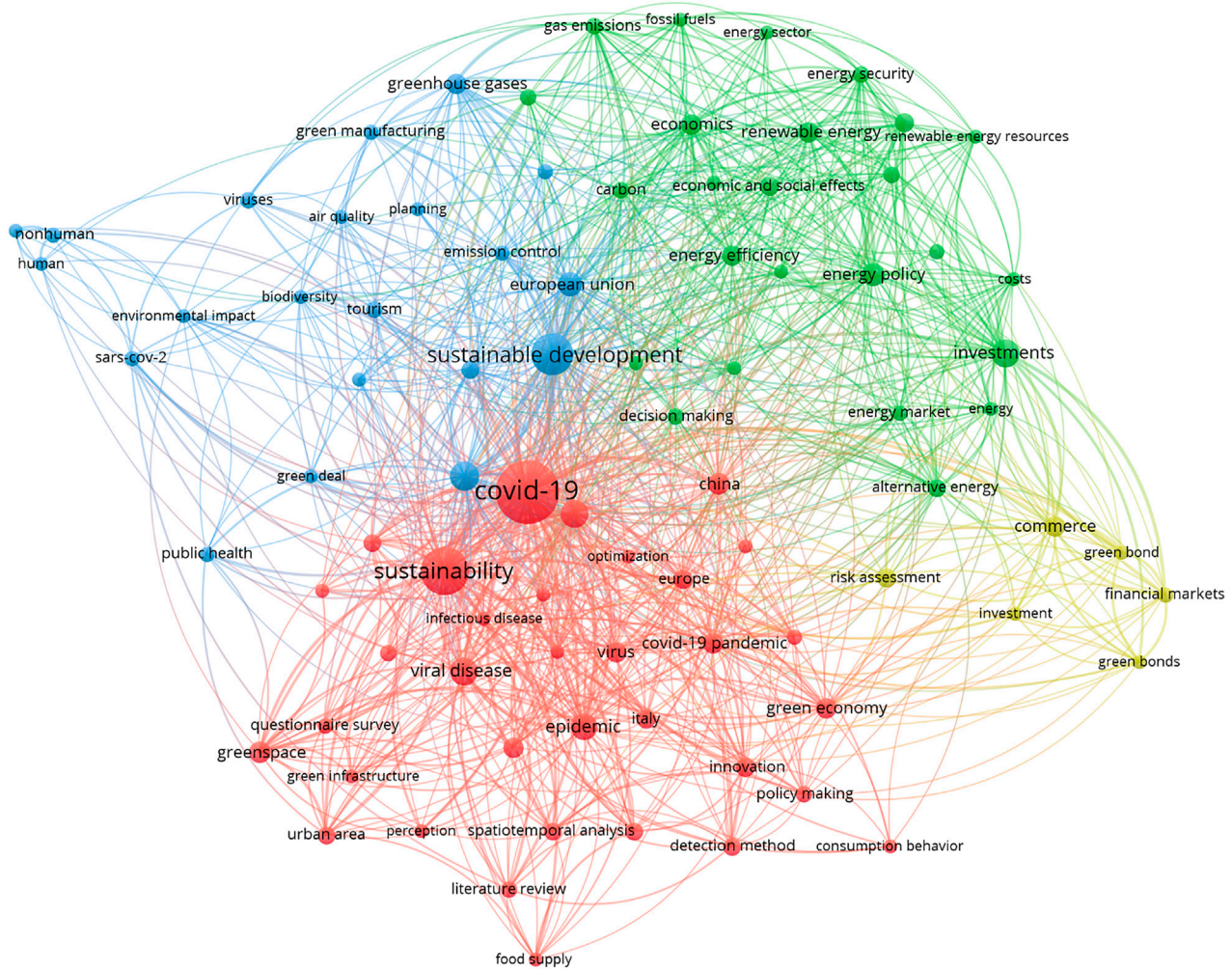

FIGURE 5 | Co-occurrence network.

post-COVID-19 sustainable growth (Bărbulescu et al., 2021), and transitions towards green strategies (Lee and Woo, 2020).

Energy security and sustainable development goals for social and economic development are the themes for the co-occurrence network's second cluster (green). The theme highlights the green business and objectives to harmonize sustainable development goals (Yousaf et al., 2021; Russo et al., 2021; Filatova et al., 2021) and impact, challenges, and opportunities for renewable energy production and efficiency (Gansukh, 2021; Celik et al., 2021; El Moummy et al., 2021; Wang et al., 2021). Green practices and public health protection represent the thematic foundations for the third cluster (green). It possesses the literature on sustainable development, climate change, and public health policies (Reinwald et al., 2021; Bayulken et al., 2021; Klioutchnikov et al., 2021; Sifa et al., 2021; Cole, 2020; Lyytimäki et al., 2020). The fourth theme provides direction toward financial markets and deals with green finance and investment strategies. The literature provides risk assessment strategies and control with the help of green financial instruments (Chakrabarti and Sen, 2021; Fu and Ng, 2021).

5 CONCLUSION

Green energy has become a topic of interest for scholars and policymakers in the recent pandemic era. The world is paying more attention to adopting green practices to deal with environmental challenges. However, the transition process is slow due to a lack of investment in eco-friendly energy projects. The government is trying to involve the private sector in green energy projects such as photovoltaic electricity generation, hydrogen, and fuel cell technologies after the outbreak of COVID-19. However, it requires lots of effort and finances in the implementation process. The academicians are also working in the same line to create awareness and signify energy efficiency's importance. The literature on the topic is

overwhelming, and it is difficult for the researchers to build a constructive view. That is why the current study conducted a bibliometric analysis to give a comprehensive view of the topic.

The study examined the significance of green energy efficiency in the post-COVID-19 era to deal with environmental deregulation. Data were extracted from the Scopus database (2020–2022) in energy, and almost 73% of the included documents were articles. China is the most influential country at the global level, followed by Italy, the UK, and the United States, which significantly contributed to the literature. However, in terms of citations, Italy gained a prominent place. At an institutional level, Nazarbayev University is the most contributing institution that the University of Cambridge, the National Research Centre, and the Sapienza University of Rome follow. Finally, sustainability is a top-ranked journal, where almost 58% of articles related to the topic were published. Conversely, the collaboration between the authors, countries, and institutions has increased over time.

The study provides research streams and themes with the help of bibliometric coupling and co-occurrence networks. The research streams provide direction in the specific research area, and research themes provide segmentations of what has been done. The study found three research streams; the first research stream directs the literature towards sustainable green business, supply chain, and food security strategies in a pandemic. The second research stream represents the post-COVID-19 environment and strategies for green infrastructure management. The third research stream is related to green infrastructure dynamics in social distancing during COVID-19. The study highlights the four highly contributing research themes. The first research theme provides sustainable, innovative, and strategic green policies in the epidemic era. The second research theme is energy security and sustainable development goals for social and economic development. The third theme is related to green practices and public health protection, and green finance, investment, and risk management are included under the fourth theme.

6 POST-COVID-19 OPPORTUNITIES FOR ENERGY EFFICIENCY

The COVID-19 pandemic has drastically changed the world's focus on green energy adoption. Although, the government, international, and local organizations have become more active in environmental issues after the Paris climate agreement and the UN Summit. However, the transition process was slow. The COVID-19 pandemic has provided a great opportunity to re-think, re-establish, and re-enforce the new energy policy towards low carbon emission, green efficiency, and renewable energy projects. In many economies, the projects of photovoltaic electricity generation, hydrogen, and fuel cell are either developmental or implementational. So, there is a need to develop a regulatory framework to promote and implement such projects. Green energy projects require a considerable amount of funding. Therefore, there is a need to involve the private sector in such projects. Governments should motivate the financial sector to promote green finance, green credit, green bonds, and other eco-friendly financial instruments to support a green economy. Subsidies and tax exemptions could be offered to eco-friendly energy projects. Furthermore, financial support should be provided to the research and development activities to explore innovative and cheap energy renewal methods that enhance energy efficiency.

7 LIMITATIONS OF THIS STUDY

This study also faces some limitations that are essential to address to enhance the scope of the study. First, the data were extracted from the Scopus database. Even though it is a reliable source, the researchers still believe that future scholars can use the combinations of databases such as Scopus and Web of Sciences to get a more comprehensive view of the topic. Second, the study is based on quantitative data, which cannot access the quality or content of the publications. That is why few of the publications included in the analysis did not directly address the energy efficiency topic. Instead, they mainly address the topic of environmental deregulation and climate change. Third, the analysis is conducted at one point in time the results of the search query may change over time.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

KK performed conceptualization, designed the research, and completed the write-up of influential aspects. AN provided data analysis and conceptual framework. Conceptualization, editing, curation, and investigation were carried out by TR.

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Assessment of Critical Factors Influencing Consumers' Acceptance of Wearable Sports Devices During COVID-19 Pandemic Conditions

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Amid rising COVID-19 stringency measures, sedentary behavior has been intensified globally, leading to intense chronic diseases. Due to the potential health benefits associated with digital wearables, there is a dire need to explore the crucial determinants for consumers, which could enhance the usage of sports wearables in addressing health challenges. For this purpose, a novel conceptual framework was developed, and Partial Least Square-Structural Equation Modelling (PLS-SEM) was employed on the primary data of 463 consumers from China. The results revealed a positive association of consumer innovativeness, perceived credibility, perceived ease in using sports wearables, perceived usefulness in using sports wearables, social influence for sports wearables, health benefits, and hedonic motivation for sports wearables during COVID-19 with the adoption intention of sports wearables. The study findings offer valuable policy recommendations to minimize COVID-19 health risks by efficiently monitoring consumers' health status.

Keywords: consumers, COVID-19, sports devices, behavior, attitude

INTRODUCTION

The emergence of COVID-19 as a global pandemic has severely affected individuals' lifestyles (Huang et al., 2022; Shi et al., 2022), social, fitness (Hussain et al., 2022; Tang et al., 2022), and health well-being (Iqbal et al., 2021; Razzaq et al., 2021b; Wang et al., 2021). For the containment of the virus, numerous measures were taken by the local and international law enforcement agencies and government institutions (Yang et al., 2021; Ahmad et al., 2022; Wen et al., 2022), including placement of lockdown, restraint of social gathering, home confinements, and the complete prohibition on the opening and use of the exercise and sports amenities to contain the virus spread (Curtis et al., 2021; Yu et al., 2021; Irfan et al., 2022a; Khan et al., 2021). Though these measures effectively control the virus spread, it has brought people serious health issues (Shahzad et al., 2021; Wu et al., 2021; Xuefeng et al., 2021).

Moreover, during this situation, technology has played a supportive role through online and remote work and the virtual offices and classrooms (Elavarasan et al., 2021; Irfan and Ahmad 2022; Javed et al., 2022). However, during that period, because of the inactivity of the people, a certain behavior was also intensified across the globe (Irfan and Ahmad 2021; Irfan et al., 2021; Irfan et al.,

2022b). It should be noted that an individual is said to be physically inactive if he does not comply with the global recommendations of exercise, which is 150–300 min weekly, whereas a person is said to have a sedentary behavior when he only expenses out a lower level of energy (Irfan et al., 2022a), which is supposed to be any value less than 1.5 METS (Thivel et al., 2018). Those people who possess sedentary behavior are more prone to having a number of chronic cardio-metabolic diseases, including obesity, cancer, ischemic heart diseases, and even early mortality (Booth et al., 2012; González et al., 2017). Furthermore, because of the higher screen time and work-from-home policies and work initiatives, an increase in sedentary behavior and inactivity has been reported in the pandemic period (Hall et al., 2021; Silva et al., 2021). Therefore, there was an intense need to have certain solutions that could reduce the risks and possibilities of having or leading to such chronic diseases (Panicker and Chandrasekaran, 2022).

One of the potential solutions among the alternatives is the wearable sports devices available for health and fitness. The term "wearable" has been explained as "any body-born computer that provides useful services while the user performs other tasks", whereas this category of the products includes smart wears, smartwatches, activity trackers, pedometers, and so on (Wilde et al., 2018). In addition to this, as there has been a rapid advancement in the products in terms of technological products which are enabled by Internet of Things (IoT), the potential number of users have enhanced the wearables' market value with the value of USD 32.63 billion, whereas it is also expected that the compound growth between the time frame of 2020–2027 will be 15% annually (Research, 2020). Moreover, there is also an increment in the popularity of these wearables because of the monitoring and evaluating real-time information that also addresses sedentary behavior (Weizman et al., 2020).

Although wearables are being built and powered by the latest technologies and the advancements are regularly being done, the data from the wearables are less valid and inferior, while compared with the accelerometers that are research-based, a major chunk of the research is being documented highlighting and discussing the validity and reliability of the outcome generated through these wearables devices (Byun et al., 2016; Huang et al., 2016), the dynamics of the markets (Wu et al., 2017), and implementation and design issues (Markovic et al., 2013; Zheng et al., 2014). However, during the pandemic, the usage and consumption of these devices have tremendously been increased (Ammar et al., 2021; Ang et al., 2021; Capodilupo and Miller, 2021). Therefore, because of the potential health benefits associated with the usage of these wearables, there is a need to explore the crucial determinants for the consumers, which could play an enhancing role in using the sports wearables. By knowing this, the markets and product developers will be better positioned to incorporate these elements within the product offerings. Hence, the current study attempts to address the following research questions.

RQ1: What are the important determinants of usage and adoption of sports wearables, especially for health and fitness purposes?

RQ2: To what extent are the determinants capable of affecting the usage and adoption of sports wearables, especially for health and fitness purposes?

The remaining study's arrangement is that the next section discusses the important determinants and their relationships in the light of the literature, followed by the methodology and statistical estimations upon which lastly, the conclusions and recommendations have been drawn.

LITERATURE REVIEW

Consumer Innovativeness, Perceived Credibility (PCR), and Adoption Intention

Consumer innovativeness (CIN) refers to the aptitude and attitude of the individuals willing to try or check any newer product or technology to be used for their utility (Agarwal and Prasad, 1997). It is among the few determinants upon which researchers agree on its importance and essentiality, especially in technologically innovative products (Ali et al., 2021; Tanveer et al., 2021). Because of the presence of this phenomenon within individuals, consumers are found to be more inclined and willing in terms of seeking knowledge, adopting, accepting, and eventually using a particular product faster, while comparing with the other individuals that have lower levels of CIN (Ahmad et al., 2021). In addition to this, CIN is also termed as differentiating factor in characterizing the lifestyle of the individuals, as though this marketers can segregate their desired target groups and devise advertisement that is more focused and target-oriented (Yi et al., 2006; Cheung et al., 2021). In addition to this, consumers must rely on it for accepting any sort of technology and find it credible and trustworthy to be used (Cheung et al., 2021). Moreover, it becomes crucial to have a high level of CIN because for the newer technology and certain aspects being new and innovative. Therefore, when consumers have an aptitude for CIN, they will develop their level of PCR towards that technology (Aldas-Manzano et al., 2009; Cheung et al., 2021). Furthermore, through this PCR, there will be an improvement in the level of adoption intention also (Chouk and Mani, 2019). Therefore, it is assumed that when consumers are high on their level of innovativeness, it will also enhance the PCR and the level of adoption (Cheung et al., 2021). Hence, it is proposed that:

H1: Consumer innovativeness leads to enhance the level of perceived credibility.

H2: Consumer innovativeness leads to enhance the level of adoption intention.

H3: Perceived credibility leads to enhance the level of adoption intention.

Consumer Innovativeness, Perceived Ease of Using Sports Wearables and Adoption Intention

Perceived Ease of Use (PEU) is one of the two constructs proposed in Technology Acceptance Model (TAM) by Davis (1989). This theory revolves around exploring the individual factors that are essential to have the adoption of any technology (Mehrad and Mohammadi, 2017; Kim and Chiu, 2019; Talukder et al., 2019). As per the

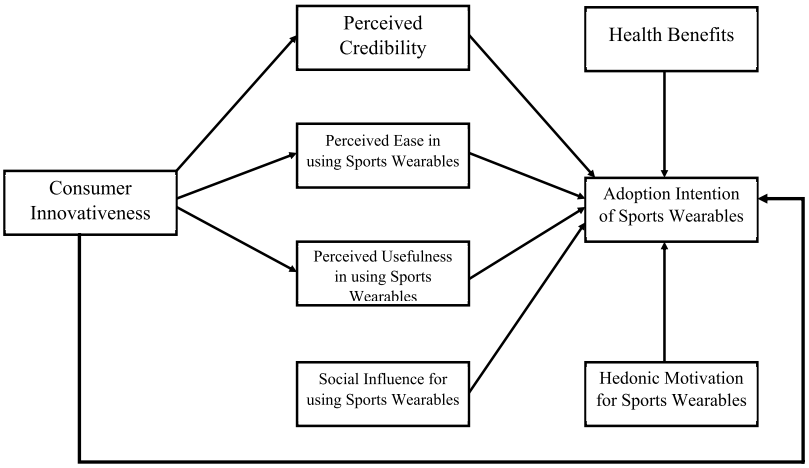

FIGURE 1 | Framework of the study.

theoretical foundations of TAM, PEU has been explained as the level of easiness and comfort that an individual perceives while dealing with and adopting newer technology (Tan and Lau, 2016). Moreover, PEU has been evaluated in different technological contexts like mobile banking (Tan and Lau, 2016) and retailing technologies (Ng et al., 2019), whereas the most relevant application is being reported in healthcare wearable devices (Cheung et al., 2021; Hao et al., 2021). In relation to CIN, PEU has been studied by the researchers who confirmed the presence of its positive association in the context of artificial intelligence (Kuo and Yen, 2009; Abbasi et al., 2022). In contrast, according to Natarajan et al. (2017), CIN can strengthen the level of PEU in the context of artificial intelligence. Similarly, in the context of the current study, it is assumed that when consumers are high on innovativeness, it will also enhance the PEU and the level of adoption (An et al., 2021; Cheung et al., 2021). Hence, it is proposed that:

H4: Consumer innovativeness leads to enhance the level of Perceived Ease of Use.

H5: Perceived ease of use leads to enhance the level of Adoption Intention.

Consumer Innovativeness, Perceived Usefulness in Using Sports Wearables, and Adoption Intention

Perceived Usefulness in Using (PUU) is the second of the two constructs proposed in TAM by Davis (1989). As per the theoretical foundations of TAM, PUU has been explained as the level of enhancement that technology brings in the performance of an individual while using or consuming it (Mehrad and Mohammadi, 2017; Kim and Chiu, 2019; Talukder et al., 2019). Similar to PEU, PUU, being the other important determinant of adoption has been equally explored by the researchers in different technological contexts including mobile banking (Tan and Lau's, 2016), retailing technologies (Ng et al., 2019), online purchasing. and most importantly in healthcare wearable devices (Cheung et al., 2021). Additionally, its relevancy within the context of artificial intelligence-based technology is endorsed by multiple researchers, including Kuo and Yen (2009) and Natarajan et al. (2017). Similarly, in the context of the current study, it is assumed that when consumers are high on innovativeness, it will also enhance the PUU and the level of adoption (Cheung et al., 2021). Hence, it is proposed that:

H6: Consumer innovativeness leads to enhance the level of Perceived Usefulness.

H7: Perceived Usefulness leads to enhance the level of Adoption Intention.

Social Influence and Adoption Intention

Social influence (SIN) has been explained as the level of impact that an individual perceives, which changes and alters his attitudes, thoughts, and decisions regarding any aspect of an act as an outcome of communicating with any other individual from the social systems (Rashotte, 2007). In this category, the individuals who belong to the social system include family, friends, peers, and acquaintances tend to influence an individual's decision (Irani et al., 2007). Especially at the initial stage of any technology, SIN has reported to have a higher level of influence on any individual (Teo and Pok, 2003; Chandio et al., 2021). In the context of wearable technologies for health and fitness, SIN has been reported as an enhancer that significantly influences the adoption intention of an individual (Miltgen et al., 2013; Gao et al., 2015). In addition to this, in the context of wearable technologies, individuals take a decision regarding the purchase and select the most appropriate device after having a discussion with the fellow people, as that individual is newly exposed to those products and want to reduce the possibilities of risks associated (Talukder et al., 2019). Hence, it is proposed that:

H8: Social influence leads to enhance the level of Adoption Intention.

Health Benefits and Adoption Intention

Sports wearables technological products come with features that are related to monitoring and checking different parameters that improve the health well-being, including steps taken, quality of

TABLE 1 | Source of measures.

Constructs	Number of items	Sources
Consumer innovativeness	3	Talukder et al. (2019)
Perceived credibility	4	Zhang et al. (2017)
Perceived ease in using sports wearables	4	Kim and Chiu (2019)
Perceived usefulness in using sports wearables	3	Zhang et al. (2017)
Social influence for sports wearables	3	Talukder et al. (2019)
Health benefits	4	
Hedonic motivation for sports wearables	3	Talukder et al. (2019)
Adoption intention of sports wearables	3	Chuah et al. (2016); Zhang et al. (2017)

sleep, distance traveled, and so on, whereas it also assists in estimating and comparing the future outcome with the history (Canhoto and Arp, 2017). In addition to this, it also helps reduce the destructive activities to human health, such as smoking and obesity. In contrast, it also assists in motivating the help of certain metrics and performance index readings (Lee and Lee, 2018). Moreover, it can also provide data sharing to the service providers through which the data is gathered on a real-time basis by which there will be a reduction in the health costs and increment in the health benefits (HBN). Hence, because of the HBN associated with the usage of such devices, they are more likely to enhance the adoption intention (Lee and Lee, 2018; Chuah, 2019). Hence, it is proposed that:

H9: Health benefits lead to enhance the level of Adoption Intention.

Hedonic Motivation and Adoption Intention

Hedonic motivation (MOT) has been explained as the level of enjoyment, fun, and pleasure extracted from the consumption and usage of any technological product or service (Venkatesh et al., 2012; Chuah, 2019; Xiang et al., 2022). It has been interchangeably used with perceived enjoyment as both have similar operational definitions (Talukder et al., 2019; Khan et al., 2021; Islam et al., 2022). Despite its proposition in the theoretical framework of "Unified Theory of Acceptance and Use of Technology" by Venkatesh et al. (2012), its relationship with usage has been reported as crucial and important by numerous researchers (Bruner and Kumar, 2007; Alnawas and Aburub, 2016; Rauf et al., 2021). In the context of sports wearables, individuals are more likely to have a higher level of MOT as it is quite related to a healthy lifestyle and is assumed to enhance adoption and usage (Gao et al., 2015; Talukder et al., 2019; Razzaq et al., 2021a). This is because during the consumption and usage of such devices, since the user is getting real-time outcomes regarding their fitness and health, they are found to be using it more frequently (Wei, 2014). Hence, it is proposed that:

H10: Hedonic motivation leads to enhance the level of Adoption Intention.

METHODOLOGY

For operationalizing any research, there are multiple options available to the researcher in terms of research approaches, including qualitative, quantitative, and mixed approaches. The researcher has to choose among the available alternative approaches based on the nature and objectives of the study. Therefore, for the current study, the most relevant and relatable approach is the quantitative research approach. This approach facilitates the researchers to collect quantitative data through which the outcome is generated, which is more objective than the findings generated from the qualitative research. Additionally, with the help of this research, the research findings can be scalable and generalizable over the larger population based on the sharing attributes and features with the collected sample (Cooper et al., 2006).

TABLE 2 | Descriptive statistics.

		Frequency	Percent
Gender	Female	201	43
	Male	262	57
	Total	463	100
		Frequency	Percent
Age	20 or less years	129	28
	21–30 years	174	38
	31–40 years	109	24
	41 and above	51	11
	Total	463	100
		Frequency	Percent
Education	Undergraduate	101	22
	Graduate	195	42
	Post graduate	129	28
	Others	38	8
	Total	463	100

Source: Authors' Estimation.

Within the quantitative research approach, there are different research designs among them. The most followed and used in social and management sciences is the survey research design. In this research design, the data collection is made through the survey questionnaire, which can either be structured or unstructured, whereas it can also be self-administered or guided. However, in this research design, there is a higher possibility of capturing unwanted variance. Hence, the propositions and guidelines by Hulland et al. (2018) were thoroughly followed while designing the survey methodology.

On the other hand, quantitative researchers in general and survey methodology, in particular, is not assumed to be immune to any of the unwanted variances as identified by Podsakoff et al. (2003), who termed it as "Common Method Variance (CMV)". The absorption and occurrence of CMV cannot be restricted;

TABLE 3 | Measurement model results.

Variables	Items	Factor loadings	Cronbach's alpha	Composite reliability	AVE
Consumer innovativeness	CIN1	0.808	0.783	0.787	0.538
	CIN2	0.833			
	CIN3	0.775			
Perceived credibility	PCR1	0.720	0.767	0.813	0.598
	PCR2	0.718			
	PCR3	0.806			
	PCR4	0.813			
Perceived ease in using sports wearables	PEU1	0.785	0.753	0.762	0.546
	PEU2	0.821			
	PEU3	0.789			
	PEU4	0.808			
Perceived usefulness in using sports wearables	PUU1	0.715	0.707	0.816	0.613
	PUU2	0.790			
	PUU3	0.774			
Social influence for sports wearables	SIN1	0.819	0.709	0.795	0.641
	SIN2	0.745			
	SIN3	0.797			
Health benefits	HBN1	0.794	0.764	0.769	0.601
	HBN2	0.841			
	HBN3	0.730			
	HBN4	0.776			
Hedonic motivation for sports wearables	MOT1	0.827	0.704	0.836	0.531
	MOT2	0.762			
	MOT3	0.761			
Adoption intention of sports wearables	INT1	0.817	0.755	0.842	0.613
	INT2	0.802			
	INT3	0.789			

Source: Authors' Estimation.

however, it can be minimized. Therefore, Podsakoff et al. (2012) have listed numerous procedural operations to reduce the occurrence. These include using easy-to-understand expressions in the questions, giving the respondents the least mental stress, while answering the questions. Additionally, the placement of a temporal gap enables the respondents to have a break, while responding to the questions. Therefore, based on these guidelines, the few demographics questions were placed in between the questions gauging the predictors and criterion variables. For easy comprehension, the experts' help was sought to identify the removal of certain jargon. After incorporation, the questionnaire was found easy to go. However, this step is unnecessary since the study utilizes the adapted scales identified from the literature. However, because of the geographical and contextual change of these questions and to minimize the CMV, this content and face validity was ensured by the panel of 10 experts, including both subject experts and linguistics. Moreover, in terms of scale, all of the questions seeking responses for the studied phenomena mentioned in **Figure 1** were measured on the level of agreement of 5-point Likert scales, where "1 represents strongly disagree", "2 represents disagree", "3 represents neither disagree nor agree", "4 represents agree", and "5 represents strongly agree". The details of the sources from where the adaptation was made is listed in **Table 1**.

Initially, 1000 questionnaires were circulated among the people who wear and prefer to wear sports wearables to improve their. However, only 553 were returned from them. On those 550, the data screening was done following the guidelines and procedures thoroughly discussed by Hair et al. (2010). The operations of data screening procedures include the identification of univariate and multivariate outliers. Hence, during this process, 90 responses were discarded. This led to the final sample of 463 respondents.

Additionally, for countering CMV, Podsakoff et al. (2012) have also proposed the application of certain statistical remedies. The idea was if the maximum variance is being explained by only one or a couple of variables, then the dataset is said to have an inflated presence of variances, findings from which could lead to biased and inferior illogical conclusions. Hence, one of the most widely used statistical remedies to ascertain the level of CMV is test proposed by Harman's (1967), which is being applied in multiple studies in social and management sciences. The findings from the application of this test lead to the conclusion that CMV is not found to be present in the dataset.

Considering the demographics of the final data (463 questionnaires), 201 responses were female, whereas 57% of the data (262responses) were male. In terms of age, 28% of the data (129 responses) were found to have an age of less than 20 years, 38% of the data (174 responses) were found to have an age between 21 and 30 years, 24% of the data (109 responses) were found to have an age between 31 and 40 years, and 11% of the data (51 responses) were found to have an age more than 41 years. The last demographic question seeks the answer of the educational background. For this, 22% of the data

TABLE 4 | Results of loadings and cross loadings.

Variable	CIN	PCR	PEU	PUU	SIN	HBN	MOT	INT
Consumer innovativeness	0.808	0.438	0.444	0.373	0.377	0.296	0.303	0.295
	0.833	0.334	0.391	0.387	0.358	0.317	0.371	0.367
	0.775	0.330	0.401	0.421	0.434	0.448	0.402	0.338
Perceived credibility	0.362	0.720	0.438	0.300	0.433	0.252	0.390	0.418
	0.417	0.718	0.386	0.348	0.293	0.339	0.448	0.340
	0.353	0.806	0.310	0.277	0.369	0.387	0.404	0.368
	0.392	0.813	0.343	0.312	0.283	0.350	0.424	0.438
Perceived ease in using sports wearables	0.333	0.345	0.785	0.310	0.424	0.344	0.420	0.331
	0.442	0.275	0.821	0.421	0.273	0.308	0.329	0.408
	0.382	0.310	0.789	0.257	0.310	0.399	0.402	0.440
	0.377	0.444	0.808	0.272	0.327	0.266	0.332	0.345
Perceived usefulness in using sports wearables	0.350	0.414	0.282	0.715	0.260	0.352	0.283	0.341
	0.438	0.261	0.369	0.790	0.378	0.387	0.363	0.288
	0.382	0.419	0.328	0.774	0.384	0.387	0.281	0.265
Social influence for sports wearables	0.436	0.252	0.413	0.351	0.819	0.292	0.347	0.364
	0.326	0.408	0.393	0.256	0.745	0.385	0.256	0.326
	0.355	0.389	0.359	0.342	0.797	0.369	0.413	0.270
Health benefits	0.372	0.352	0.415	0.353	0.357	0.794	0.362	0.327
	0.415	0.441	0.283	0.304	0.411	0.841	0.314	0.412
	0.400	0.275	0.261	0.319	0.370	0.730	0.450	0.415
	0.430	0.288	0.283	0.360	0.384	0.776	0.446	0.426
Hedonic motivation for sports wearables	0.448	0.346	0.364	0.254	0.368	0.429	0.827	0.324
	0.338	0.359	0.261	0.324	0.336	0.357	0.762	0.267
	0.433	0.293	0.328	0.384	0.266	0.434	0.761	0.305
Adoption intention of sports wearables	0.284	0.355	0.413	0.310	0.346	0.331	0.270	0.817
	0.445	0.298	0.305	0.428	0.317	0.268	0.251	0.802
	0.376	0.273	0.268	0.432	0.422	0.311	0.415	0.789

Source: Authors' Estimation.

(101 responses) were found to have an education of undergraduate level, 42% of the data (195 responses) were found to have an education of graduate level, 28% of the data (29 responses) were found to have an education of postgraduate level, and 8% of the data (38 responses) were found to have an education other than the mentioned level. The details of the demographics of the final data are listed in **Table 2**.

ANALYSIS AND RESULTS

Following the framework, the current study comprised of multiple criterion variables at different levels. Such models and their operationalization are relatively difficult and complex to handle by the conventional first-generation techniques like regression analysis. Therefore, the techniques belonging to the second-generation category are preferable and recommendable in such complex modelling where there is an involvement of multiple predictors and criteria and the aim of the model is to explain the variance. In addition to this, within the second-generation category, the technique which has the capability to explain more variation of the model which is, at the same time complex as well the most recommended approach is considered to be Partial Least Square-Structural Equation Modelling (PLS-SEM) (Hair et al., 2019). Among the alternate software application available in the market, the application with the most user-friendly interface is developed, which is named SmartPLS.

In terms of PLS-SEM application, the current research follows the statistical guidelines discussed by Hair et al. (2016). The application of PLS-SEM should be made after getting quality clearance through the assessment at two levels. These include the assessment at the level of the measurement model, which reflects the outer model, and at the level of the structural model, reflecting the outer model. After meeting the requirements for the quality clearance, the conclusions drawn from the findings can be considered legitimate and valid.

Assessment of Measurement Model

As suggested by Hair et al. (2016), the first level involves the assessment of the measurement model, in which three are two parameters that need to be evaluated further. These include convergent validity, which is the reflection of the level of inter-connectedness that the measurement items of a construct possess, which integrates it to form a construct, and the discriminant validity, which is the reflection of the level of inter-disconnectedness that the measurement items of a construct possess with the measurement items of another construct which enables them to form different constructs. In convergent validity, the present study considers three parameters: internal consistency, factor loadings, and "Average Variance Extracted" (AVE). For internal consistency, Hair et al. (2016) stated that the acceptable value is more than 0.7 for both Cronbach's Alpha and Composite Reliability, which is found in the present study as listed in **Table 3**. For factor loadings, Hair et al. (2016) stated that the acceptable value is also more than 0.7

TABLE 5 | Discriminant validity Fornell–Larcker criterion.

	CIN	PCR	PEU	PUU	SIN	HBN	MOT	INT
CIN	0.733							
PCR	0.584	0.773						
PEU	0.552	0.563	0.739					
PUU	0.519	0.534	0.620	0.783				
SIN	0.609	0.596	0.521	0.540	0.800			
HBN	0.520	0.627	0.530	0.627	0.600	0.775		
MOT	0.598	0.620	0.579	0.525	0.611	0.613	0.728	
INT	0.592	0.530	0.566	0.594	0.598	0.623	0.621	0.783

Source: Authors' Estimation

TABLE 6 | Results of HTMT ratio of correlations.

	CIN	PCR	PEU	PUU	SIN	HBN	MOT	INT
CIN								
PCR	0.663							
PEU	0.789	0.635						
PUU	0.622	0.703	0.656					
SIN	0.692	0.608	0.798	0.738				
HBN	0.545	0.744	0.653	0.626	0.608			
MOT	0.762	0.799	0.523	0.531	0.586	0.635		
INT	0.586	0.543	0.554	0.665	0.699	0.715	0.621	

Source: Authors' Estimation.

as presented in **Table 3**. For AVE, stated that the acceptable value is more than 0.5, also found in the present study as listed in **Table 3**.

For discriminant validity, the current study has the assessment through three criteria. First, through the cross-loadings. This is the loadings of a particular factor against other factors, that is why it is called cross-loadings. Though a factor should be highly loaded within its own construct, the loadings against other constructs should be minimal. However, Gefen and Straub (2005) have suggested that the acceptable value of the difference between loadings and cross-loadings is 0.1. The details of the cross-loadings of the data are listed in **Table 4**.

The second criteria used for assessing discriminant validity are the most frequently and vastly used criteria: Fornell and Larcker (1981) criterion. As per these criteria, the correlation values among the construct should be less in drawing a comparison with the square root of AVE. Through this, there is a reflection of the discrepancy of the constructs from the other constructs. Referring to **table 5**, the values which are highlighted and are placed at the diagonal positions are the square root of AVE, whereas the values other than these are the inter-construct correlations among the constructs. The listed values clearly indicate the meeting of the criteria.

Lastly, the discriminant validity was also assessed and validated by newly proposed criteria by Henseler et al. (2015), which is named as "Heterotrait-Monotrait ratio of correlations" (HTMT). For this criterion, the proposition where the data complies to the presence of discriminant validity by Henseler et al. (2015) is 0.85. The listed values of HTMT in **Table 6** indicate the criteria's meeting.

TABLE 7 | Predictive power of construct.

	R-Square	Q-Square
PCR	0.157	0.101
PEU	0.172	0.098
PUU	0.154	0.094
INT	0.350	0.127

Source: Authors' Estimation.

TABLE 8 | Results of path coefficients (direct effects).

Hypothesized path	Path coefficient	C.R	*p*-value	Remarks
CIN → PCR	0.187	8.729	0.000	Supported
CIN → PEU	0.202	6.942	0.000	Supported
CIN → PUU	0.151	7.910	0.000	Supported
CIN → INT	0.134	5.794	0.000	Supported
PCR → INT	0.196	6.782	0.000	Supported
PEU → INT	0.187	5.438	0.000	Supported
PUU → INT	0.119	7.083	0.000	Supported
SIN → INT	0.195	5.651	0.000	Supported
HBN → INT	0.106	8.995	0.000	Supported
MOT → INT	0.152	5.087	0.000	Supported

Level of significance (5%, i.e., 0.050).
Source: Authors' Estimation.

Assessment of Structural Model

This level involves assessing the inner model in which the capability of predictability and predictive relevancy of the model is evaluated by two parameters. These are known as "coefficient of determination" and "Cross-Validated Redundancy". For the coefficient of determination which is indicated by R-Square , Cohen (1988) is of the opinion that if the generated value is greater than 0.26, then it should be considered as substantial, and if it is less than 0.02, then it should be considered as weak, whereas any value in between should be considered as moderate. On the other hand, "Cross-Validated Redundancy" is indicated by Q-Square and is computed by following the Stone Geisser's methodology. For this parameter, Hair et al. (2016) suggested accepting any value greater than zero. The listed values of Q-Square and R-Square in **Table 7** indicate the assessment of both the parameters.

Hypotheses Testing

To assess the relationships among the studied phenomena proposed in Literature Review and its respective significance, PLS-SEM follows the bootstrapping methodology. This methodology computes the significance by drawing multiple subsamples from the data. After reaching the desired number of subsamples, Hair et al. (2016) proposed 5000 subsamples. The significance is computed. This is also one advantage of using PLS-SEM over other types of SEM techniques. Nevertheless, the relationships and the generated outcome are discussed as follows, listed in **Table 8**.

For the relationship between consumer innovativeness and perceived credibility, a significant and positive relationship is reported with the beta coefficient of 0.187, at a 1% level of significance ($\beta = 0.187$, $p < 0.01$). This means that consumer

innovativeness will play a role in improving the perceived credibility by 18.7%. This is the reflection of the aptitude of the consumers that when they have the willingness, capability, and understanding of being innovative, it will improve their level of reliance overusing the sports wearables in order to monitor, assess, improve, and control their level of fitness and healthy well-being. For the relationship between consumer innovativeness and perceived ease of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.202, at a 1% level of significance ($\beta = 0.202$, $p < 0.01$). This means that consumer innovativeness will improve the perceived ease of using sports wearables by 20.2%. This is the reflection of the aptitude of the consumers that when they have the willingness, capability, and understanding of being innovative, it will reduce the possibility of hardships and anxiety of using the sports wearable and will improve their inner competency that resulted in providing easiness of using the sports wearables in order to monitor, assess, improve, and control their level of fitness and healthy well-being. For the relationship between consumer innovativeness and perceived usefulness of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.151, at a 1% level of significance ($\beta = 0.151$, $p < 0.01$). This means that consumer innovativeness will improve the perceived usefulness of using sports wearables by 15.1%. This is the reflection of the aptitude of the consumers that when they have the willingness, capability, and understanding of being innovative, it will reduce the negatives associated with using the sports wearable and will improve their inner competency that resulted in providing usefulness of using the sports wearables to monitor, assess, improve, and control their level of fitness and healthy well-being. For the relationship between consumer innovativeness and intention of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.134, at 1% level of significance ($\beta = 0.134$, $p < 0.01$). This means that consumer innovativeness will improve the perceived usefulness of using sports wearables by 13.4%. This is the reflection of the aptitude of the consumers that when they have the willingness, capability, and understanding of being innovative, it will reduce the adversities associated with using the sports wearable and will improve their inner competency that resulted in improving their willingness and intention of using the sports wearables to monitor, assess, improve, and control their level of fitness and healthy well-being.

For the relationship between perceived credibility and intention of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.196, at a 1% level of significance ($\beta = 0.196$, $p < 0.01$). This means that consumers' perceived credibility will play a role in improving the level of intention of using sports wearables by 19.6%. This is the reflection of the aptitude of the consumers that when they perceive the usage of sports wearables reliable, credible, and have a certain level of reliance and confidence of using it, it will reduce the hardships associated with using the sports wearable and will improve their inner competency that resulted in improving their willingness and intention of using the sports wearables to monitor, assess, improve, and control their level of fitness and healthy well-being. For the relationship between perceived ease of using sports wearables and intention of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.187, at a 1% level of significance ($\beta = 0.187$, $p < 0.01$). This means that consumers' perceived ease of using sports wearables will play a role in improving the level of intention of using sports wearables by 18.7%. This is the reflection of the aptitude of the consumers that when they perceive the usage of sports wearables easy, simple, and free from any complexity while using it, it will reduce the adversities associated with using the sports wearable and will improve their inner competency that resulted in improving their willingness and intention of using the sports wearables in order to monitor, assess, improve, and control their level of fitness and health well-being. For the relationship between perceived usefulness of using sports wearables and intention of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.119, at 1% level of significance ($\beta = 0.119$, $p < 0.01$). This means that consumers' perceived usefulness of using sports wearables will play a role in improving the level of intention of using sports wearables by 11.9%. This is the reflection of the aptitude of the consumers that when they perceive the usage of sports wearables beneficial, helpful, and worthy for using it, it will reduce the hardships associated with using the sports wearable and will improve their inner competency that resulted in improving their willingness and intention of using the sports wearables to monitor, assess, improve, and control their level of fitness and health well-being.

For the relationship between perceived social influence of using sports wearables and intention of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.195, at a 1% level of significance ($\beta = 0.195$, $p < 0.01$). This means that consumers' perceived social influence for using sports wearables will play a role in improving the level of intention of using sports wearables by 19.5%. This is the reflection of the aptitude of the consumers that when they perceive a social pressure from their friends, family, social circle, and acquaintances for using the sports wearables, it will reduce the adversities associated with using the sports wearable and will improve their inner competency that resulted in enhancing their willingness and intention of using the sports wearables to monitor, assess, improve, and control their level of fitness and healthy well-being. For the relationship between perceived health benefits of using sports wearables and intention of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.106, at 1% level of significance ($\beta = 0.106$, $p < 0.01$). This means that consumers' perceived health benefits for using sports wearables will play its role in improving the level of intention of using sports wearables by 10.6%. This is the reflection of the aptitude of the consumers that when they perceive the benefits of using the sports wearables in their health, including physical, psychological, and mental well-being for using the sports wearables, it will reduce the hardships associated with using the sports wearable and will improve their inner competency that resulted in improving their willingness and intention of using the sports wearables to monitor, assess, improve, and control their level of fitness and healthy well-being. Lastly, for the

relationship between perceived hedonic motivation of using sports wearables and intention of using sports wearables, a significant and positive relationship is reported with the beta coefficient of 0.152, at a 1% level of significance ($\beta = 0.152$, $p < 0.01$). This means that consumers' perceived hedonic motivation for using sports wearables will play its role in improving the level of intention of using sports wearables by 10.6%. This is the reflection of the aptitude of the consumers that when they perceive the benefits of using sports wearables are enjoyable, fun, pleasurable, and exciting, it will reduce the adversities associated with using the sports wearable and will improve their inner competency that resulted in improving their willingness and intention of using the sports wearables in order to monitor, assess, improve, and control their level of fitness and healthy well-being (Razzaq et al., 2021a, b).

CONCLUSION AND RECOMMENDATION

During the worldwide spread of COVID19, technology has played a supportive role through online and remote work and the virtual offices and classrooms. However, the inactivity of people led to sedentary behavior. People who possess sedentary behavior are more prone to chronic cardiometabolic diseases, including obesity, cancer, ischemic heart diseases, and even early mortality. Therefore, there was an intense need to have specific solutions that could reduce the risks and possibilities of having or leading to such chronic diseases. One of the potential solutions among the alternatives is the wearable sports devices available for health and fitness. Because of the potential health benefits associated with the usage of these wearables, there is a need to explore the crucial determinants for the consumers, which could play an enhancing role in using the sports wearables.

Hence, the current study attempts to identify the important determinants of usage and adoption of sports wearables, especially for health and fitness purposes. Based on the thorough literature review, a conceptual framework was developed. For the empirical analysis, Partial Least Square-Structural Equation Modelling (PLS-SEM) was applied on the data set of 463 consumers. The results reported the positive association of consumer innovativeness; perceived credibility; perceived ease in using sports wearables; perceived usefulness in using sports wearables; social influence for sports wearables; health benefits; Hedonic motivation for sports wearables with the adoption intention of sports wearables.

Based on the findings, the present study proposes multiple recommendations. First, markets and development of the wearables should identify and target the group with a higher level of innovativeness, as this group is more inclined to purchase and use sports wearables. Additionally, more focused advertisements need to be done to cater to the needs of the people from the same target group. Second, there is a need to improve the calculated estimations from these variables despite being powered by artificial intelligence and the internet of things. These wearables are still producing the least reliable and inferior results. With the help of this, the credibility of the consumers will eventually be increased, which will also be benefitted for the consumers. Last, manufacturers, developers, and marketers need to work on the interface of these wearables, as when it becomes more user-friendly, it will eventually have more acceptance among users.

Considering the limitations, future researchers are recommended to explore other determinants like trust, price value, and users' habits. For this purpose, exploring through theoretical models like theory of planned behavior and UTAUT will expand the literature of wearables. Additionally, more research is required, especially on the built-in technology and the minimized advancements through discrepancies and invalidity. Last, there is a need to explore asymmetric relationships among the studied variables. This can be done through the estimation techniques built on the framework of machine learning and artificial intelligence.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study was approved by the ethics committee of the Zhejiang Yuexiu University, China (No. 876-4). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PH: conceptualization, writing—original draft, formal analysis, data handling, variable construction and methodology, writing—review and editing. YS: writing—review and editing. TA: supervision. NN: software, methodology, writing—review and editing, WS: writing—review and editing.

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How Does Environmental Regulation Affect Green Innovation? A Perspective From the Heterogeneity in Environmental Regulations and Pollutants

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Green (technical) innovation is expected to be an effective tool for addressing environmental crises. However, the effect of environmental regulations on green innovation may depend on the type of environmental regulation. To that end, this study utilizes panel data covering 30 Chinese provinces to explore the mechanism underlying the relationship between these two variables in light of the heterogeneity in environmental regulations and pollutants. The direct effects of three types of environmental regulations and four pollutants are verified, as are the thresholds in the effects of environmental regulations on green innovation. The results show that 1) both market-incentive and public participation-based environmental regulations have positive effects on green innovation, while command-and-control regulations do not. Unlike the effects of the market-incentive tool, which has a single threshold, the effect of public participation-based environmental regulations has two thresholds, which indicates that there is too little public participation for such regulations to be effective and too much for them to be sensitive to environmental protection. 2) Three of the four pollutants (industrial wastewater, waste gas, and carbon emissions) have a significantly positive impact on green innovation only when they exceed the first threshold value, whereas an increase in industrial solid waste has little effect on green innovation until it exceeds the second threshold value. 3) In the eastern region, all three kinds of environmental regulations play significant roles in promoting green innovation, and their effects are greater than those in the western region. However, the effect of environmental regulations in the central region is not different from that in the western region.

Keywords: environmental regulation, green innovation, threshold effect, pollutant reduction, panel threshold model

1 INTRODUCTION

Since the global spread of the COVID-19 pandemic, severe environmental degradation and high carbon emissions have threatened China's economic development and carbon neutrality goals (Chen et al., 2020a; Wu et al., 2020a; Irfan et al., 2021a; and Chuxiao Yang et al., 2021). The large amounts of waste water, waste gas, and waste solids generated by industrial production have brought about great harm to the lives and health of residents. It is estimated that the total number of deaths caused by air pollution (for example, long-term exposure to PM2.5) exceeded 30 million from 2000–2016. In addition, China's carbon emissions reached 10 billion tons in 2020, accounting for one-third of the total global emissions. This is a substantial challenge to achieve the goals of carbon peak and carbon neutrality. Under such circumstances, green (technical) innovation is expected to be an effective tool for dealing with environmental crises. However, due to the large amount of capital required and the high level of investment risk, polluting enterprises have not prioritized green innovation to reduce emissions. Therefore, different environmental regulation tools have been implemented by the government to encourage or guide green innovation activities. However, the ways in which different types of environmental regulations affect green innovation need to be further studied. Addressing these issues is crucial to protecting the environment and improving China's sustainable development capabilities.

Environmental regulations are an important policy tool for achieving governmental targets and guiding enterprise production and operational activities (Zhang and Song, 2021). In general, there are three types of environmental regulatory tools: command-and-control regulations, market-incentive regulations, and public participation-based regulations. These tools have different characteristics. First, as a traditional method for implementing environmental controls, command-and-control regulations are mandatory measures formulated by the government to directly affect the emission-reduction activities of polluters, while market-incentive environmental regulations mainly rely on price or cost mechanisms; such regulations include environmental pollution taxes, subsidies, and tradable license, which guide producers and consumers toward more energy-saving and environment-friendly options (Xie et al., 2017; Chen et al., 2020b). For example, Xie et al. (2017) confirmed that the productivity effect driven by market-based regulations is much stronger than that of the command-and-control.

In contrast with the aforementioned two environmental regulatory tools designed by the government, public participation-based environmental regulations mainly rely on practices driven by public awareness of environmental protection, such as the reporting of environmental violations to superiors to exert pressure on polluting enterprises (Ge et al., 2021; Johnson, 2020). Of the three tools, command-and-control environmental regulations are the most popular tool in many developing countries for their simplicity and high efficiency, although such regulations have been criticized for their extremely large economic efficiency losses (Tang et al., 2020). Compared with command-and-control measures, market-incentive tools have greater flexibility and encourage cleaner enterprises through financial support to improve their competitiveness. Regarding public participation-based regulations, some studies have proven that public participation does affect pollutant emissions and environmental performance (Zhao et al., 2022; Stucki et al., 2018; Irfan et al., 2021b). This method is not the main means of regulation in developing countries due to the lack of a clear channel for the expression of public opinion.

Some current studies focus on the mechanism or effects of environmental regulations on green development (Hao et al., 2021). For example, Liu et al. (2021) confirmed that command-and-control environmental regulations and voluntary environmental regulations affected green innovation, mainly at the technology R&D stage, while market-based environmental regulations influenced the entire process of green innovation activities. Hui Peng et al. (2021) confirmed that geographical proximity accelerates the diffusion of green knowledge and technology and then stimulates the intention and enthusiasm of enterprises towards green innovation. Li et al. (2021) argued that environmental regulation is positively correlated with green innovation. However, the relationship between them is influenced by economic policy uncertainty. However, Hao et al. (2018) confirmed that current environmental control measures and regulations have not achieved the desired goal of controlling and reducing pollution using the city-level panel data of 283 Chinese cities, and the direct impact of FDI on China's environment is negative, suggesting that there is evidence for the pollution haven hypothesis. Furthermore, environmental decentralization has a negative moderating effect of environmental regulation on the green total factor energy efficiency (Wu et al., 2020b). Chen et al. (2018) believed that an increase in the proportion of corrupt officials may weaken environmental regulation, which would consequently lead to an increase in illegal production and total pollutant emissions.

Green innovation can be defined as new or improved processes, technologies, systems, or products intended to reduce or prevent environmental problems (Franceschini et al., 2016; Rennings, 2000). Such innovations can reduce pollution emissions, optimize resource utilization, improve ecological management (Xu et al., 2021; Qiuyue Yang et al., 2021; and Tang et al., 2022), and increase firm competitive advantage (Xie et al., 2019; Díaz-García et al., 2015). The relationship between environmental regulations and green innovation can be summarized as follows: *1*) Positive effects*:* the Porter hypothesis holds that appropriate environmental regulations can stimulate technical innovation among enterprises, thereby promoting their economic and environmental performance (Porter and van der Linde, 1995). This has been verified by scholars (e.g., Curtis and Lee, 2019; Dong et al., 2019; and Yang et al., 2020). For example, Jing Peng et al. (2021) proved that under strict environmental regulations, geographical proximity accelerates the diffusion of green knowledge and technology, thus stimulating enterprises' willingness and enthusiasm for green innovation. Liu et al. (2021) investigated the impact of China's new Environmental Protection Law on green innovation

behavior of listed companies in high-polluting industries and found that companies tended to apply for more environmental patents after the implementation of the new Environmental Protection Law. *2)* Negative effects*:* some scholars believe that due to the increased compliance costs brought by environmental regulations, enterprises lack green innovation funds. Yuan et al. (2017) concluded that environmental regulations crowd out R&D investments in the manufacturing industry and, thus, cannot fully encourage technological innovation and ecological efficiency improvements in the manufacturing industry. Jorgenson and Wilcoxen (1990) proposed that strict environmental regulations can reduce pollution emissions quickly, but they may also cause economic development to slow down due to higher production costs. *(3)* Nonlinear effects*:* the effect of environmental regulations on green innovation depends on the intensity of the regulation. Specifically, the effects may be insignificant in the early stages, but may become significant once regulatory intensity exceeds a threshold (Jing Peng et al., 2021; Li and Du, 2021). Wu et al. (2020a) confirmed that the nonlinear effect depends on the specific type of environmental decentralization, and the decentralization of environmental supervision and monitoring leads to a negative impact on the green total factor energy efficiency.

Green innovation is a complex process because its pre-conditions include a wider range of material resources, external knowledge, and information resources (Costantini et al., 2017; De Marchi, 2012). Considering the diversity in the types and intensity of environmental regulations, a wide variation in their effects on green innovation are expected (Albrizio et al., 2017; Guo and Yuan, 2020; and Xie et al., 2017). Not only do environmental regulations affect the intensity of green innovation, but the characteristics of pollutants do as well. For example, compared with air pollution, solid waste pollution receives far less attention. Therefore, its impact on green innovation is not obvious because the environmental regulations aimed at reducing solid waste are relatively mild. In light of this, this study proposes a comprehensive method of comparison to explore the potential impact of environmental regulations on green innovation that accounts for the heterogeneity in environmental regulations and pollutants. This study makes three contributions: 1) Few studies have explored the mechanism by which environmental regulations impact green innovation from the perspective of the heterogeneity in pollutants and environmental regulations. This study combines these two sources of heterogeneity into a unified research framework to provide an in-depth analysis of the mechanisms linking pollutants, environmental regulation, and green innovation. 2) Taking 30 Chinese provinces and regions from 1995 to 2018 as the sample, panel data models are used to explore the direct effects of environmental regulations on green innovation. 3) In view of the potential nonlinearities in this relationship, this study employs a panel threshold model to check for thresholds in the effects of three environmental regulation tools and four pollutants. The findings in turn provide a meaningful reference for a more comprehensive understanding of the role of different types of environmental regulations.

The remainder of the article proceeds as follows: **Section 2** introduces the methodology used in the investigation of the relationship between environmental regulations and green innovation. **Section 3** presents the relevant data and indicators used in the model. **Section 4** reports the empirical results for the 30 Chinese regions from 1995 to 2018, and **Section 5** summarizes the main findings and possible policy implications.

2 METHODOLOGY

2.1 Panel Regression Models

The panel regression model can effectively mitigate the omitted variable bias caused by potential unobserved individual and time factors (Xiao et al., 2018). It is an extremely powerful tool for causal inference. Therefore, it is employed to check the direct effect of environmental regulations on green innovation. According to the aforementioned discussion, green innovation, environmental regulation, and pollution are the main variables we are concerned about. Therefore, the fixed-effect panel regression model to verify the impact of environmental regulations on green innovation is as follows:

$$GI_{it} = \alpha_0 + \alpha_1 ER_{it} + \alpha_2 PL_{it} + \beta \cdot Z_{it} + \mu_i + \delta_t + \varepsilon_{it}, \quad (1)$$

where i and t represent the individual and time, respectively. GI_{it} represents the green innovation of individual i in year t, ER_{it} represents the means of environmental regulation, PL_{it} is different types of pollution, Z_{it} refers to a series of control variables that affect green innovation, α_0 is the constant term of the model; α_1 and α_2 are the coefficient vectors of environmental regulations and pollution to be estimated, β is the coefficient vector of the control variables, u_i and δ_t are the individual fixed effects and the time fixed effects, respectively, and ε_{it} is an error term, which represents the random disturbance.

Since 2006, the environmental regulation policy has become more stringent, which is mainly reflected in two aspects: on the one hand, the central government began to implement "total emission quantity control"; on the other hand, environmental quality became a key indicator for officials' political promotions. To check the time effect before and after 2005, this study introduces the time dummy variable T, which takes the value 1 if the observation year is after 2005; otherwise, 0. Model (1) is modified to the following model:

$$GI_{it} = \alpha_0 + \alpha_1 ER_{it} + \alpha_2 PL_{it} + \beta \cdot Z_{it} + \mu_i + \theta \cdot T + \varepsilon_{it}. \quad (2)$$

In this study, we choose 30 provinces in mainland China as our sample. In view of the great differences among regions in terms of resource endowment, economic development, and human capital, the sample is divided into eastern, central, and western regions according to its geographic location (please see **Supplementary Appendix Table A** for details), and the corresponding regression model is as follows:

$$GI_{it} = \alpha_0 + \alpha_1 ER_{it} + \alpha_2 PL_{it} + \beta \cdot Z_{it} + \varphi_1 \cdot D_1 + \varphi_2 \cdot D_2 + \delta_t + \varepsilon_{it}, \quad (3)$$

where the dummy variable D_1 is set to 1 if the individual belongs to the eastern region; otherwise, it is 0. With the same logic, D_2 is

TABLE 1 | Specific setting of variables.

Variable	Symbol	Description	Units
Green innovation	*GI*	The number of green invention patents granted	Number
Local regulation	*REG*	The number of laws and legislations in the regions	Number
Reporting cases	*REP*	Number of reports of environmental violations	Number
Pollution protection funds	*PPF*	Environmental pollution control funds by the government	10^4 Yuan
Industrial structure	*INDS*	The ratio of the added value of the second industry to GDP	%
Human capital	*HUM*	The number of students in universities per 10,000 population	%
Energy intensity	*EE*	The proportion of total energy consumption to GDP	%
Carbon emission	CO_2	Energy-related carbon emissions	Tonnes
Waste water discharge	*X1*	The amount of waste water discharge	10^4 tonnes
Waste gas emissions	*X2*	The amount of waste gas emissions	Tonnes
Industrial solid waste	*X3*	The amount of industrial solid waste	10^4 tonnes
Science and technology investment	*TECH*	The ratio of science and technology investment to GDP	%

TABLE 2 | Descriptive statistics of variables.

Variables	Obs	Mean	Std. dev	Min	Max
lnGI	720	3.676	2.193	0	8.626
lnREG	720	2.376	1.304	0	5.872
lnREP	720	9.225	1.637	2.303	13.249
lnPPF	720	11.35	1.361	6.615	16.142
lnINDS	720	3.738	0.211	2.806	4.126
lnHUM	720	9.182	0.841	6.71	10.706
lnEE	720	−0.844	0.796	−3.026	0.694
$lnCO_2$	720	9.872	0.999	6.705	11.955
lnX1	720	10.803	0.956	8.147	12.599
lnX2	720	12.962	0.95	9.353	14.381
lnX3	720	8.206	1.155	4.234	10.727
lnTECH	720	−5.767	1.983	−15.038	−1.896

denoted 1 if it is located in a certain region; otherwise, it is set to 0. Thus, φ_1 measures the difference in green innovation between the eastern and western regions, and φ_2 measures this difference between the central and western regions.

2.2 Panel Threshold Regression Models

Proposed by Hansen (1999), the threshold regression model can test and estimate certain kinds of nonlinear relationships between the outcome and predictors. The impact of environmental regulations on green innovation may be a threshold effect. In other words, only when environmental regulation exceeds a certain threshold will enterprises be encouraged to carry out green innovation. To explore such a non-linear relationship, a threshold panel regression model is established as follows:

$$GI_{it} = \alpha_0 + \alpha_1 ER_{it} \cdot I\left(PL_{it} < \gamma_1\right) + \alpha_2 ER_{it} \cdot I\left(PL_2 \geq \gamma_1\right) + \beta \cdot Z_{it} + \varepsilon_{it} \tag{4}$$

where $\mathrm{I}(\cdot)$ is an indicator function; that is, when the formula in brackets is established, its value is 1, and otherwise, its value is 0. γ_1 are the specific threshold values to be calculated; different types of pollution PL_{it} are threshold variables; and ER_{it} are regime variables. α_1 and α_2 represent the slope threshold effect of ER_{it} on PL_{it} under different GI_{it} intervals. Other symbols are similar to model (3).

Eq. 4 represents the single threshold panel model. However, in most cases, there may be multiple thresholds between variables. Assuming there are two thresholds, the model is set as

$$y_{it} = \alpha_0 + \alpha_1 ER_{it} \cdot I\left(PL_{it} < \gamma_1\right) + \alpha_2 ER_{it} \cdot I\left(\gamma_1 < PL_{it} < \gamma_2\right) + \alpha_3 ER_{it} \cdot I\left(PL_2 < \gamma_2\right) + \beta \cdot Z_{it} + \varepsilon_{it} \tag{5}$$

For the existence of the threshold effect, taking model (4) as an example, we can make the following null hypothesis:

$$H_0\colon \alpha_1 = \alpha_2 \tag{6}$$

If the null hypothesis cannot be rejected, the relationship between the two variables is linear, which can be estimated using ordinary estimation methods, such as LSDV. Otherwise, we can use the LR test to judge the existence of the threshold effect. The LR statistics are as follows:

$$LR = \frac{\left[SSR^* - SSR\left(\hat{\gamma}\right)\right]}{\hat{\sigma}^2} \tag{7}$$

where SSR^* is the residual sum of squares under the null hypothesis H_0 and $SSR\left(\hat{\gamma}\right)$ is the residual sum of squares with no constant term. $\hat{\sigma}^2 = \frac{SSR(\hat{\gamma})}{n(T-1)}$ is the unbiased estimator of ε_{it}.

3 DATA AND INDICATORS

3.1 Dependent Variables

Green innovation is the dependent variable in this study. There are two popular indicators to measure green innovation: one is *the number of green patent applications*, and the other is *the number of green patents granted* (e.g., Brunnermeier and Cohen, 2003; Cai et al., 2020; and Li et al., 2018). A patent application is a request that is to be granted to a patent pending at the patent office, while a granted patent is one that has been granted by a national or regional patent office. Thus, this article uses *the number of green invention patents granted* as the proxy of green innovation because it more accurately reflects the ability of green innovation. According to the previous literature (Bansal and Clelland, 2004; Li et al., 2018), we collected the related data from the database of the State Intellectual Property Office of China. If the full text of a patent contains the keywords "low

TABLE 3 | Matrix of correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) lnREG	1.000	—	—	—	—	—	—	—	—	—	—
(2) lnREP	0.486	1.000	—	—	—	—	—	—	—	—	—
(3) lnPPF	0.480	0.544	1.000	—	—	—	—	—	—	—	—
(4) lnINDS	0.070	0.219	0.418	1.000	—	—	—	—	—	—	—
(5) lnHUM	0.501	0.550	0.634	0.362	1.000	—	—	—	—	—	—
(6) lnEE	0.033	0.046	0.206	0.491	0.563	1.000	—	—	—	—	—
(7) $lnCO_2$	0.282	0.237	0.461	0.246	0.204	−0.120	1.000	—	—	—	—
(8) lnX1	0.395	0.489	0.520	0.570	0.843	0.594	0.132	1.000	—	—	—
(9) lnX2	0.231	0.314	0.555	0.702	0.675	0.768	0.210	0.736	1.000	—	—
(10) lnX3	0.329	0.388	0.700	0.498	0.662	0.522	0.341	0.542	0.756	1.000	—
(11) lnTECH	0.107	0.142	0.046	−0.185	0.017	−0.263	0.387	−0.032	−0.074	−0.073	1.000

carbon," "green," "environment," "emissions reduction," "energy-saving," "clean," "sustainable," "recycling," "saving," "ecology," "environmental protection," or "environmental pollution," it is regarded as a green innovation patent. Through this method, we collected the data on *the number of green utility model patents granted* and *the number of green invention patents granted* and classified them into different regions according to the applicant's address information.

3.2 Variables of Interest

Environmental regulation and pollution are the variables of interest in this study. To explore the heterogeneous impacts on green innovation, we choose a variety of environmental regulatory measures, including command-and-control, market-incentive policy and public participation-based environmental regulations. The corresponding proxy variables are as follows: command-and-control regulation is represented as *the number of regional laws and legislations*, market-incentive policy is represented as *environmental protection funds by the government*, and public participation-based environmental regulation is measured as the *number of reports of environmental violations*.

In addition to environmental regulations, another interesting variable we are concerned about is pollution. Here, we choose four types of emissions, including *wastewater, waste gas, industrial solid waste,* and *carbon emissions.* The former three types of pollution come from the China Statistical Yearbooks, and carbon emissions need to be estimated through seven fossil fuels using the method recommended by IPCC (2006).

TABLE 4 | The impact of environmental regulations on green invention patents.

Variables	(1)	(2)	(3)
lnREG	0.0400	—	—
	(1.5601)	—	—
lnREP	—	0.0284**	—
	—	(2.1459)	—
lnPPF	—	—	0.0943***
	—	—	(3.1168)
lnINDS	0.0428**	−0.0703**	−0.0850**
	(0.1483)	(−0.2488)	(-0.3020)
lnHUM	2.3560***	2.3195***	2.3240***
	(10.6106)	(10.5845)	(10.6687)
lnEE	1.8128***	1.7762***	1.7585***
	(11.8095)	(11.7265)	(11.6488)
$lnCO_2$	1.4614***	1.4562***	1.3696***
	(13.2978)	(13.3735)	(12.4301)
lnX1	0.2833**	0.2831**	0.2922**
	(2.5006)	(2.5453)	(2.6364)
lnX2	0.0172**	0.0016**	0.0235**
	(2.1566)	(3.0143)	(4.2176)
lnX3	0.0383	0.0283	−0.0138
	(0.4109)	(0.3057)	(−0.1482)
lnTECH	0.1006***	0.0932**	0.1017***
	(2.7219)	(2.5413)	(2.7911)
_cons	−30.6162***	−30.5874***	−29.8819***
	(−13.5470)	(−13.6755)	(−13.3643)
N	701	701	701
R^2	0.9033	0.9051	0.9059

The t value is in ().
****Significance at the levels of 1%*
***Significance at the levels of 5%*
**Significance at the levels of 10%. Symbols have the same meaning below.*

3.3 Control Variables

In this study, some influencing factors on green innovation, such as industrial structure (*INDS*), science and technology investment (*TECH*), human capital (*HUM*), and energy intensity (*EE*), are chosen as control variables. The specific introduction for those control variables is as follows.

Industrial structure (*INDS*): this study uses the ratio of the added value of the secondary industry in GDP to represent the industrial structure (Chen et al., 2021). Since China's secondary industry is dominated by high-pollution and high-energy consuming sectors, a higher value of the industrial structure means more serious environmental pollution and a stronger driving force for green innovation (Du et al., 2021).

Human capital (*HUM*): innovative activities are inseparable from the support of human capital. High-quality human capital provides an intellectual contribution to innovative capabilities, and so it is positively related to green innovation. In this article, human capital is measured by the ratio of college students per 10,000 persons.

Energy intensity (*EE*): energy intensity is usually measured by the proportion of total energy consumption to GDP. Since the energy structure is dominated by fossil energy, the higher the

TABLE 5 | The time effect of environmental regulations on green utility model patents.

Variables	(1)	(2)	(3)
lnREG	0.0743	—	—
	(1.2932)	—	—
lnREP	—	0.0365***	—
	—	(2.6383)	—
lnPPF	—	—	0.0706***
	—	—	(3.1504)
lnINDS	0.7220***	0.5636***	0.5669***
	(3.7402)	(2.9299)	(2.9551)
lnHUM	2.0226***	2.0699***	2.0744***
	(13.6376)	(13.8960)	(13.9985)
lnEE	1.4312***	1.4627***	1.4740***
	(13.9016)	(14.1021)	(14.3721)
$lnCO_2$	0.5569***	0.5617***	0.5344***
	(7.1946)	(7.1878)	(6.7685)
lnX1	0.2454***	0.2774***	0.2700***
	(3.2423)	(3.6607)	(3.5649)
lnX2	0.5074***	0.5181***	0.5327***
	(7.1755)	(7.2628)	(7.5211)
lnX3	0.0871	0.0951	0.0780
	(0.7718)	(0.8633)	(0.5488)
lnTECH	0.0928***	0.0907***	0.0920***
	(3.8257)	(3.7097)	(3.7724)
T	0.1893***	0.1805***	0.1493**
	(2.9029)	(2.7272)	(2.3018)
_cons	−20.8509***	−21.2071***	−21.0306***
	(−13.5749)	(−13.7229)	(−13.6089)
N	720	720	720
R^2	0.9275	0.9263	0.9266

*Note: The t value is in (). ***, **, and * indicate significance at the levels of 1%, 5%, and 10%, respectively.*

TABLE 6 | Regional heterogeneity analysis estimated results.

Variables	(1)	(2)	(3)
lnREG	0.0547	—	—
	(1.4805)	—	—
lnREP	—	0.1074***	—
	—	(4.6058)	—
lnPPF	—	—	0.1768***
	—	—	(5.0381)
lnINDS	0.1841	0.0359	0.0277
	(0.5164)	(0.1071)	(0.0748)
lnHUM	2.3607***	2.2568***	2.3127***
	(8.6601)	(9.0993)	(9.5200)
lnEE	1.7381***	1.6825***	1.6995***
	(7.8671)	(8.2597)	(8.1693)
$lnCO_2$	0.9392***	0.7952***	0.8071***
	(4.1394)	(4.1360)	(4.0095)
lnX1	−0.2318	−0.2422	−0.2442
	(−1.1072)	(−1.2705)	(−1.1923)
lnX2	1.6699***	0.3099*	2.1680***
	(8.9017)	(1.8087)	(8.2923)
lnX3	0.1351	0.1706	0.1026
	(0.8108)	(1.0814)	(0.6612)
lnTECH	0.0664	0.0396	0.0584
	(1.0977)	(0.6054)	(0.9206)
t1	0.4550***	0.5633***	0.4430***
	(3.7234)	(4.4813)	(3.8515)
d1	1.0501**	0.9064**	0.9805**
	(2.4400)	(2.2962)	(2.4216)
d2	−0.2296	−0.2384	−0.2348
	(−0.4717)	(−0.5777)	(−0.5477)
_cons	−27.3027***	−25.8380***	−26.2146***
	(−10.0836)	(−9.9795)	(−11.0419)
N	701	701	701

*Note: The t value is in (). ***, **, and * indicate significance at the levels of 1%, 5%, and 10%, respectively.*

energy intensity is, the more severe environmental pollution and the higher the demand for green innovation.

Science and technology investment (*TECH*): ehe government's science and technology investment is helpful to relax the financial constraints of enterprises, thereby providing more funds to conduct green innovation activities (Zhang et al., 2020) Therefore, it is expected to have a positive effect on green innovation. In this study, the ratio of science and technology investment to the GDP is used to measure the intensity of science and technology investment.

3.4 Sample and Data

Because the data for some regions, such as Tibet, Hong Kong, Macao, and Taiwan, are not available, we choose 30 provinces in Mainland China as our samples, and the time span is from 1995 to 2018. The aforementioned data all come from the *China Statistical Yearbook, China Environment Statistical Yearbook, China Industrial Economic Statistical Yearbook, China Science and Technology Statistical Yearbook,* and provincial statistical yearbooks. To eliminate the influence of price factors, nominal variables related to currency, such as GDP, are converted into current values using the GDP price index, with 1995 as the base year. These variables are all transformed by a natural logarithm to reduce heteroscedasticity. **Table 1** shows the specific settings of the variables, and **Table 2** displays their descriptive statistics.

4 RESULTS AND DISCUSSION

Before the regression model, a multi-collinearity test must be carried out. As shown in **Table 3**, the independent variables are highly, linearly related to the dependent variables, and the correlation between independent variables is low. This indicates that the multi-collinearity problem does not exist in the estimation process.

4.1 Direct Effect Analyses

This study uses the fixed-effect panel model to investigate the direct impact of environmental regulations on green innovation. The results of the direct effect with *lnGI* as the dependent variable are shown in **Table 4**. In general, except for command-and-control regulations (Ln*REG*), all environmental regulation tools have played a positive role in promoting green innovation. This indicates that government efforts to reduce emissions are conducive to green innovation. However, we find that the coefficients of the command-and-control regulations are not significant. The main reason is that although pollutant

TABLE 7 | Bootstrap test of the threshold effect (the regime variable is *lnREG*).

Threshold variables	Model	F-statistics	*p* value	1%	5%	10%	BS
CO_2	Single threshold	29.97	0.007	18.983	21.489	27.095	300
X1	Single threshold	26.8	0.023	16.389	21.911	29.964	300
X2	Single threshold	24.86	0.013	14.136	17.331	25.911	300
X3	Single threshold	21.61	0.043	17.491	21.547	27.646	300
	Dual threshold	18.12	0.05	14.490	18.088	26.218	300

The p *value and the critical value are obtained by repeated sampling 300 times using the threshold bootstrap method.*

TABLE 8 | Threshold estimation and its confidence interval.

Threshold variables	Model	Threshold estimator	Lower	Upper
CO_2	Single threshold	18360.25	17445.69	18433.13
X1	Single threshold	5066	4602.5	56139.5
X2	Singe threshold	400947	393880.5	405353
X3	Single threshold	3477	3364.59	3522
	Dual threshold	4710.67	4577.35	4730.8

TABLE 9 | Threshold effect of different pollutants.

Variables	Threshold variables		—	—
	CO_2	X1	X2	X3
lnINDS	0.0381	0.1818	0.0722	0.1486
	(0.1365)	(0.6606)	(0.2582)	(0.5315)
lnHUM	2.0564***	2.2159***	2.2167***	2.2016***
	(9.5198)	(10.3483)	(10.2570)	(10.1693)
lnEE	1.9549***	1.9383***	1.8728***	1.9407***
	(13.5693)	(13.3794)	(12.8745)	(13.3912)
$lnCO_2$	1.3732***	1.2982***	1.4306***	1.3999***
	(13.2842)	(12.4594)	(13.8489)	(13.5028)
lnX1	0.2647**	0.3492***	0.2715**	0.2825**
	(2.4170)	(3.1792)	(2.4684)	(2.5584)
lnX2	−0.0976	0.1552**	0.4171***	0.2859***
	(−0.9468)	(2.0070)	(7.7290)	(3.1233)
lnX3	0.0833	0.1520*	0.0499	0.0201
	(0.9616)	(1.7355)	(0.5750)	(0.2307)
lnTECH	0.0738**	0.1046***	0.0784**	0.0676*
	(2.1085)	(2.9432)	(2.2323)	(1.9163)
$I(Regime \le C_1)$	0.0049	0.0201	0.0026	−0.0014
	(0.580)	(0.230)	(1.6191)	(−1.1081)
$I(C_1 < Regime \le C_2)$	—	—	—	0.0332
	—	—	—	(1.2081)
$I(C_2 < Regime)$	0.0284***	0.0738*	0.0051***	0.0049***
$orI(C_2 < Regime)$	(2.2300)	(5.56)	(5.3780)	(5.1885)
_cons	−26.7556***	−28.8131***	−28.0181***	−28.2030***
	(−12.2917)	(−13.3248)	(−12.9517)	(−13.0147)
N	720	720	720	720
R^2	0.9071	0.9090	0.9064	0.9060

*Note: The t value is in (). ***, **, and * indicate significance at the levels of 1%, 5%, and 10%, respectively.*

emissions can be reduced to a certain extent through command-and-control measures, such as production suspension or production restriction, this way of sacrificing economic development also disrupts the normal operation of enterprises and thus reduces enterprises' ability to conduct green innovations.

In addition, the coefficient of market-incentive policies (Ln*PPF*) is greater than that of Ln*REP*. The reason may be that economic incentive tools directly stimulate the enthusiasm of enterprises for green technology through funding support; however, due to the lack of a clear channel for the expression of public opinion, public participation is not seriously considered by enterprises.

For the control variables, *human capital, energy intensity, carbon emissions, wastewater discharge, waste gas emissions,* and *science and technology investment* all have a positive impact on green innovation. However, the mechanism is different between those influencing factors. Factors such as *human capital* and *science and technology investment* provide intellectual and financial support for green innovation, respectively. Other factors, such as *energy intensity, carbon emissions, wastewater discharge, and waste gas emissions,* provide demand driving forces for green innovation. The secondary industry factor provides both financial support and a demand driving force for green innovation.

Different from the positive effect of three types of pollutions (*lnCO2, lnX1, and lnX2*), the coefficient of *industrial solid waste (lnX3)* has little effect on green invention patents. The reason is that compared to other pollutants, industrial solid waste is the pollutant of least concern and can be reused (such as abandoned mines and building materials). Therefore, there are relatively few innovative activities related to industrial solid waste.

4.2 Robustness Checks

To check the robustness of the estimated results, the strategies we adopted include replacing the explanatory variable of green innovation (*lnGI*) with the number of green utility model patents (*lnGUP*), changing the samples in different periods, and replacing the explanatory variable *lnREP* with the number of local government proposals in two sessions (*lnPROP*). The estimated results are shown in **Supplementary Appendix Tables B–D**. We found that the coefficients of the three environmental regulations are still significantly positive, and the magnitude of

TABLE 10 | Bootstrap test of the threshold effect (regime variable is CO_2).

Regime variables	Threshold variables	Model	F-statistics	*p* value	1%	5%	10%	BS
REP	CO_2	Single threshold	19.89	0.067	24.744	32.184	49.024	300
		Dual threshold	21.15	0.002	13.940	16.636	22.407	300
REG		No threshold	4.97	0.65	19.781	25.040	34.2299	300
PPF		Single threshold	18.72	0.0367	12.364	16.728	23.833	300

TABLE 11 | Threshold estimation and its confidence interval.

Regime variables	Threshold variables	Model	Threshold estimator	Lower	Upper
REP	CO_2	Single threshold	18360.25	15548.07	18433.13
PPF		Single threshold	92311	70119	92432

TABLE 12 | Threshold effect of different environmental regulation methods[1].

Variables	(1)	(2)	(3)
lnINDS	0.0393	0.0381	0.1281
	(0.1415)	(0.1365)	(0.4558)
lnHUM	2.1175***	2.0564***	2.1910***
	(9.8973)	(9.5198)	(10.1160)
lnEE	1.8944***	1.9549***	1.9831***
	(12.9964)	(13.5693)	(13.5889)
$lnCO_2$	1.4250***	1.3732***	1.4096***
	(13.8337)	(13.2842)	(13.4816)
lnX1	0.2576**	0.2647**	0.2687**
	(2.3598)	(2.4170)	(2.4100)
lnX2	−0.1025	−0.0976	−0.1110
	(−0.9782)	(−0.9468)	(−1.0617)
lnX3	0.0625	0.0833	0.0708
	(0.7238)	(0.9616)	(0.8069)
lnTECH	0.0835**	0.0738**	0.0819**
lnINDS	(2.3870)	(2.1085)	(2.3079)
$I(REP \le C_1)$	−0.004	—	—
—	(−0.3115)	—	—
$I(C_1 < REP \le C_2)$	0.0002***	—	—
	(4.6790)	—	—
$I(C_2 < REP)$	0.0052	—	—
	(0.2774)	—	—
$I(REG \le C_1)$	—	0.0049	—
	—	(0.380)	—
$I(C_1 < REG)$	—	0.0284	—
	—	(0.6300)	—
$I(PPF \le C_1)$	—	—	−0.0021
	—	—	(−0.4903)
$I(C_1 < PPF)$	—	—	0.0024***
	—	—	(4.5364)
_cons	−27.5725***	−26.7556***	−28.3108***
	(−12.7545)	(−12.2917)	(−12.9691)
N	720	720	720
R^2	0.9073	0.9071	0.9044

*Note: The t value is in (). ***, **, and * indicate significance at the levels of 1%, 5%, and 10%, respectively.*

their volatility is very small in the three cases. This indicates that the previous estimation is robust.

4.3 Temporal and Regional Differences

According to **Eq. 2**, the regression results on checking the time effect are shown in **Table 5**. The coefficients of the dummy variable *T* pass the significance test at a level of less than 5%, indicating that the impact of environmental regulations on green innovation after 2005 is greater than that before 2005. This demonstrates that the increase in insensitivity to environmental regulation since 2005 has led enterprises to conduct green innovations to improve their competition for a higher profit and meet the government's environmental standards.

According to **Eq. 3**, the regression results for checking regional differences are shown in **Table 6**. In the eastern region, the three kinds of environmental regulations significantly promote green innovation, and the magnitude is greater than that in the western regions. However, the effect of environmental regulations in the central region is no different from that in the western region.

The eastern region has a sound economic, humanistic, and scientific research foundation and has advantages in forming a green innovation network and promoting the diffusion of innovation technology. Although the economic development level of the central region is slightly higher than that of the western region, the central region has no obvious advantages over the western region in terms of innovation environment or innovation capabilities.

4.4 Threshold Effect Analyses

The aforementioned discussion indicates that environmental regulation can significantly support green innovation. In this section, we further utilize the threshold regression model to test the nonlinear influencing mechanism of green innovation. To this end, four pollutants (or emissions) and three means of environmental regulation are selected as the threshold variables in this study.

4.4.1 Threshold Effect on Heterogeneous Pollutants

This section aims to verify the threshold effect of green innovation on heterogeneous pollution. Thus, four pollutants, CO_2, *X1*, *X2,* and *X3,* are selected as threshold variables, and command-and-control regulations are selected (*lnREG*) as the regime variable. Before the threshold regression, we first need to check whether there are threshold effects, and we use the bootstrap method to investigate the number of thresholds for the F-statistics. According to the results from **Table 7** and **Table 8**, the threshold effect is verified, and the corresponding threshold value is identified. We can see that CO_2, X_2, and *X3* have threshold values of 18,360.25, 5066, and 400,947 units, respectively, and *X3* has dual threshold values of 3,477 and 4,710.67 units, respectively.

Panel threshold regression models are conducted according to **Eqs 4**, **5**, and the estimated results are shown in **Table 9**. According to column (1), when CO_2 is less than the threshold value of 18,360.25, the coefficient is not significant, and when it exceeds the threshold value, the coefficient is significantly positive. The same fact is also verified by *X1* and *X2*, as shown in columns (4) and (5). This means that when the amount of emissions is too small, green innovation will not be triggered, and only when pollution becomes more serious will enterprises be forced to invest in green innovation under pressure from the government and the public. Column (5) shows that *X*3 has a dual threshold effect and that its coefficient in the first two intervals is not significant. When the value is large enough, its coefficient becomes significant. Because solid waste is not as destructive to the environment as other pollutants, a small amount of discharge will not attract the attention of the public and the government, and only when it is serious will it attract enough attention.

4.4.2 Threshold Effect on Environmental Regulation

Three environmental regulation tools, including *lnREG, lnPPF,* and *lnREP,* are selected as regime variables, and CO_2 is selected as a threshold variable in view of its wide attention in China and abroad. Following the same logic, we first check whether there is a threshold effect and identify the number of thresholds. According to the results in **Table 10**, **Table 11**, the threshold effect is verified, and the corresponding threshold value is identified. REG has no threshold effect. *PPF* has a threshold value and *REP* has a double threshold. The corresponding threshold values are listed in **Table 11**.

As shown in **Table 12**, assuming that PPF is lower than the first threshold value, its coefficients are insignificant; when it exceeds this threshold value, the coefficients become significant. This indicates that intensive environmental regulations can help to induce green innovation. With regard to *REP*, its impact mechanism is different from that of PPF. Specifically, when it is lower than the first threshold value, its regression coefficient on green innovation is not significant. When it is greater than the first threshold value but less than the second threshold value, the coefficient is significantly positive. However, once it exceeds the second threshold value, the coefficient becomes insignificant again. This demonstrates that too many or too few reports of environmental violations by the public will not promote green innovation. Only moderate exposure can promote green innovation. The reason may be that there is an optimal effect for public participation to protect the environment. Less exposure is insufficient to attract the public's or government's attention, and excessive exposure may result in the decline in the public's or government's sensitivity.

5 CONCLUSION AND POLICY IMPLICATION

This study investigates the impact of environmental regulations on green innovation in light of the heterogeneity in environmental regulations and pollutants using a sample of 30 provincial regions from 1995 to 2018. A fixed-effect regression model and a panel threshold model are used to explore the direct effects and the non-linearities in the relationship between the two variables. The following conclusions and policy implications are obtained:

1) Both market-incentive and public participation-based environmental regulations promote green innovation, and especially after 2005, the effects of market-incentive regulations have been greater than those of public participation-based regulations. These facts indicate that the pollution-reduction efforts of the government began to be conducive to green innovation after 2005. However, command-and-control regulations do not significantly induce green innovation. Therefore, the government should adopt market-incentive environmental regulation tools as much as possible instead of restricting production or imposing other measures that harm the real economy.
2) Regarding pollution, three kinds of pollutants (CO_2, *X1,* and *X2*) were found to have significant positive effects on green innovation. The results of the threshold regression indicate that the coefficients on these pollutants are not significant when they are less than the threshold value, and become significantly positive once they exceed the threshold value. This means that too low a level of emissions does not trigger green innovation, while more serious pollution forces enterprises to invest in green innovation. However, increases in *industrial solid waste* (X3) have little effect on green innovation patents. The results of the threshold regression show that only when the amount of X3 is greater than the first two threshold values does it have a significant impact on green innovation. As a result, *industrial solid waste* is the least concerning pollutant of the four pollutants studied. Therefore, there are comparatively few innovations that address industrial solid waste. This finding tells us that although green innovation is conducive to reductions in pollutant emissions, it is not suitable for inducing reductions in all types of pollutants. Whatever method leads to reduced pollutants should be encouraged.
3) In the eastern region, the three kinds of environmental regulations play significant roles in promoting green innovation, and the magnitude of their effects is greater than those in the western region. However, the effects of

environmental regulations in the central region are not different from those in the western region. This is because the eastern region has a sound foundation in economic, humanistic, and scientific research, so it has advantages in forming green innovation networks and promoting the diffusion of innovative technology. Although the economic development level of the central region is slightly higher than that of the western region, the innovation environment in the central region and its innovation capabilities are not obviously better than those of the western region. This shows that regional cooperation needs to be strengthened to induce pollution reduction. The eastern region should make use of its innovation advantages to strengthen R&D investment, and the central and western regions should introduce green technology from the eastern region to reduce pollution.

4) The results of the panel threshold regression model show that the environmental regulation tool REG has no threshold effects, while *PPF* has a threshold value. This indicates that only sufficiently intensive environmental regulations can help to trigger green innovation. However, unlike the market-incentive tool *PPF,* which has one threshold effect, the public participation-based environmental regulation *PPF* has two threshold effects, which indicates that public participation is too low to be effective and too high to be sensitive to environmental protection. The heterogeneous impacts of environmental regulations on green innovation indicate that attention must be given to the time and intensity of the environmental regulations for them to be effective. In addition, specific and appropriate tools are required in order to cope with the different types of pollutants.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and funding acquisition: ZC, XN, and XG; analysis and interpretation: ZC and XN; writing, review and editing: ZC, XG, and HC; final approval of the article: ZC, XN, HC, and XG; and overall responsibility: ZC, XN, HC, and XG.

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SUPPLEMENTARY MATERIAL

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Sustainable Energy Efficient Human-Centered Digital Solutions for ESG Megacities Development

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This study demonstrates algorithms that assist municipal administrations to make the best environmental decisions. The algorithms developed by large alpha-class municipal governments with assistance of department of environmental agency data analyst. Mathematical and econometric modeling techniques as well as optimum solution theories adhered to develop a model, and the criteria is functionality, which reflects a balance between maximum profit, comfort in living circumstances, the environment, and the need to avoid a market failure scenario. The ensuing results allow for the most optimal administrative decisions, such as the rate of environmental taxes. The empirical findings show that higher environmental, social and governance performance and digital finance has improved the corporate financing efficiency, as well as the influence of ESG performance on energy efficiency, all at a 1% significance level.

Keywords: corporate financing efficiency, digital finance, ESG performance, environmental sphere, megacities development

1 INTRODUCTION

The link between business and personal life have changed significantly since the late 1990's due to a wide range of technological improvements, rapid popularization, urbanization and geopolitical global decisions has widely impacted on the social, environmental and governance performance (Majumder et al., 2015). The active population, including children, teenagers, and the elderly, now has new chances to reach their full potential. Growing populations and younger generation have reaching to the full potential to utilize for the better future therefore, required high degree of autonomy to fulfill the futural plans and goals (Anwar et al., 2022; Su et al., 2022). The demand of the housing and energy is increased where natural resources are quickly decreasing (Ahmad et al., 2019; Yao et al., 2021; Alfahad et al., 2022). On other hand world is facing shortage of basic human amenities such as housing due to the economic chaos in many countries and the living cost has increased bad economic condition leading the human rights concerned (Alfahad et al., 2022).

Over the past few decades human migration and mobility have increased throughout Europe, both within and between states (Halbritter and Dorfleitner, 2015). The occupational organization of the population has changed, and labor force mobility has grown (Demirag, 2018). International transportation services are becoming increasingly widespread (Monciardini et al., 2020). Several businesses have seen qualitative transformations as a result of the development of the Web 4.0 concept and the general availability of high-speed access to the globe (Benchekroun et al., 2020). The expansion of the hotel, restaurant and catering (HORECA) segment (Knappe et al., 2022; Aritenang, 2021) which includes intermediary firms that organize such activities, was fueled by societal awareness and the ability to travel to any desired location anywhere in the world, including changing residence based on the availability of work or comfortable conditions. Concurrently, the environmental state has worsened substantially as a result of externalities (Antoniadou et al., 2013). Accounting for their influence is critical for economic forecasting since market failure originates from the resulting market equilibrium imbalance and violation of Pareto efficiency (La Torre et al., 2020).

Several governments have dedicated considerable focus in recent years to the long-term growth of industrial businesses. Environmental, social, and corporate governance (ESG) performance has increasingly become the most critical indication for defining a company's degree of long-term growth and giving major guarantees for commercial banks' concessional credit loans. Digital and information technologies are being integrated into the traditional banking sector (Yang et al., 2022). The conventional financial intermediary business model has given way to new business models enabled by advanced algorithms, cloud computing, 5G, and mobile internet technologies, all of which contribute to reducing financial service costs (Jitmaneeroj, 2016). By increasing channels and shortening asymmetric information, the digital solution has had a substantial impact on financial constraint reduction. Energy efficiency is greatly influenced by good environmental performance (Ahmad et al., 2019). ESG performance improves employee performance significantly with greater employee dimension appraisals (Barth et al., 2021). The investments benefit from ESG performance as defined by German standards (Zhao et al., 2021). Good ESG performance promotes corporate financial success in China and Germany, where CEO power and employees on the board of directors may support this link (Tian et al., 2022). As a result of development, ESG performance grows (Barykin et al., 2021).

In Canada, ESG performance has also been shown to mitigate the relationship between gender diversity (corporate scandals) and firm financial success (Ouni et al., 2020). Higher ESG performance increases a company's market value, whereas worse ESG performance decreases it (Chouaibi et al., 2021). Furthermore, ESG performance has been proved to lower firm financial risk during the market-wide financial crisis induced by the COVID-19 pandemic (Barrutia & Echebarria, 2021). Geographical and international variety, on the other hand, may assist to offset the negative association between a firm's ESG score and financial success (Grisales & Caracue 2021). As a result, ESG performance may help emerging economies retain their growth (Kraus et al., 2021).

Human-centered digital solutions help financial institutions, governments, and businesses of all sizes (Ouni et al., 2020). Incorporating social entrepreneurship reduces corporate risk perceptions, which might have a negative impact on energy efficiency (Aisaiti et al., 2019). Financial inclusion and financial literacy may be increased by using the internet and digital financial products.

Financial inclusion is the easy accumulation of capital, security, and a safe way to save, and it is a significant driver of economic growth (Claessens and Perotti 2007). Digital finance helps to boost the efficiency of regional financial sectors (Bowen and Pennaforte, 2017). During a financial crisis, networked digital finance might have serious economic and societal consequences. The three transmission mechanisms of loan availability, knowledge growth, and social trust acceptance are all improved by digital finance. Networking and digital signals influence corporate finance behavior positively (Guzmán-Ortiz et al., 2020). Digital inclusive finance affects household leverage ratio and digital technology implies regional income disparities (Wang et al., 2020).

Efficiency and the use of digital technologies may also have an influence on company financial capital availability and financing efficiency. The capacity of a firm to match capital availability and allocation methods is characterized as corporate energy efficiency. Previous research has mostly focused on the connection between ESG performance and company financial success. In contrast, this essay tackles the gaps in the interaction consequences of human-centered digital solutions and ESG performance on energy efficiency. This article expands on three notable developments. First, employing input and output indicators, this study evaluates energy efficiency using data envelopment analysis (DEA). The essay then delves deeper into the overall indices, digitalization level indices, coverage breadth indices, and use depth indices of digital finance. At the 1% level of significance, our empirical data show that they greatly increase firm finance efficiency. Finally, ESG performance is found to have a large beneficial effect on energy efficiency at the 1% significance level, as well as a slightly favorable influence on ESG at the 1% significance level.

2 MATERIALS AND METHODS

2.1 Mathematical Model

The COVID-19 pandemic was a black swan occurrence that broke established interaction networks and radically altered the economic landscape of the majority of towns and cities that serve as human movement hubs (Mayo et al., 2021). The impending repeal of strong quarantine measures will have a significant impact on all services, prompting regional and local governments to make well-informed and calculated decisions (Lorentzen, 2022). Furthermore, an acute manifestation of the problem connected with a lack of sufficient corporate

administrative control, which is responsible for the impact of externalities, is envisaged. The challenge for governments is to find innovative ways to establish the presence of an optimal balance between possible profit for interested parties and depreciation of environmental harm caused by their actions (Todorov, 2014). In practice, the following groupings may be recognized:

- corporate MICE (Meetings, Incentives, Conferences, and Exhibitions);
- a surge in the number of individuals wanting to attend historical political events, sporting events, holidays, festivals, and cultural and social gatherings;
- tourism, as determined by the GaWC (Globalization and World Cities Research Network) rating, which ranks cities from Alpha to Alpha ++ based on tourist attractions, POI (points of interest) density, and historical legacy;
- Health tourism (HT) is focused on medical treatment and services since the top physicians, modern hospital equipment, and research institutes are concentrated in big cities. Furthermore, in many cases, this type of tourism is motivated by a significant disparity in the expense of processes or the inability to obtain help due to legal limits in one's own country.
- Individuals and migrant workers are migrating to megacities in pursuit of improved job possibilities. It is worth mentioning that the number of accompanying dependents follows the number of ex-pats in the same order.
- Large universities, academies, and educational institutions are also located near important scientific and industrial centers, student mobility is a frequent feature of most megacities

Using quantitative data acquired automatically from the periodic reports of the hotel, restaurant and catering (HORECA) segment enterprises, a curve depicting changes in the total extra strain on the city's resources is generated (Bezerra et al., 2016). This connection is stochastic, uneven, and has a high annual frequency of demand seasonality. We breakdown this dependency into a Fourier series using mathematical analysis to divide its complex structure into many harmonic components, each of which is a periodic function. Then, in order to compute the dynamics of resource demand, we develop systems of Erlang-type differential equations.

3 RESULTS OF MATHEMATICAL MODEL

The development of a mathematical model is required in order to determine the most optimum solutions. We made use of the technology for creating a digital twin, which allows us to use the mathematical procedures that have been created to get the best possible result. We present a number of notations for the arguments that will be utilized. The load's dependency on the passage of time is referred to as. Because it varies unevenly throughout the year, reflecting the strain placed on the limited resources available in the region or the megapolis, we shall describe its breakdown as a series of elements (where). A periodicity characteristic of the burden on resources is introduced, which in real activity corresponds to the yearly cycle of the year. This enables us to use the Fourier expansion to represent the following phenomena:

$$\Lambda(t) = \Lambda_0 + \sum_{i=1}^{+\infty} \Lambda_i \, Cos\left(2\pi \frac{i}{T} t + \psi_k\right) = \sum_{i=1}^{+\infty} \lambda_i(t)$$

We make use of a mathematical apparatus that is analogous to the Erlang computer system. This is conducted by the definition of a set of values for the potential of the common resources of the land. Following that, we propose functions that define a collection of system states, as well as a set of probabilities for each of those states (Kurochkina et al., 2021).

In this expression, the terms are periodic, and the term meets the requirement, thus the statement is complete. In this view, stationary probability of occurrence is taken into consideration. Following that, we may analyze the following sequence:

$$p'_{0i}(t) = -\lambda_i(t) p_{0i}(t) + \nu_i(t) p_{1i}(t), \; p'_{1i}(t) = -\nu_i(t) p_{1i}(t) + \lambda_i(t) p_{0i}(t)$$

together with the complete group condition:

$$\sum_i p_i(t) = 1$$

after carrying out an algebraic transformation of the form:

$$p'_{0i}(t) = -[\lambda_i(t) + \nu_i(t)] p_{0i}(t) + \nu_i(t)$$

at zero conditions

$$p_{0i}(0) = \alpha_i \le 1, \; p_{1i}(0) = 1 - \alpha_i \le 1$$

it becomes possible to obtain the desired system already in quadrature's in the form:

$$p_{0i}(t) = e^{-\int_0^t [\lambda_i(x) + \nu_i(x)] dx} \left[\alpha_i + \int_0^t \nu_i(x) e^{-\int_0^x [\lambda_i(z) + \nu_i(z)] dz} dx \right]$$

based on the fact that the functions $\lambda_i(t)$ and $\nu_i(t)$ are periodic, we denote

$$\varphi_i(t) = \int_0^t [\lambda_i(x) + \nu_i(x)] \, dx$$

as well as k, which satisfies the inequality: $kT \le t < (k+1)T$.

As a result, we have an expression for the calculation of $\varphi_i(t)$:

$$\varphi_i(t) = k a_i + \int_0^\tau [\lambda_i(z) + \nu_i(z)] dz$$

here it is assumed that:

TABLE 1 | List of variables.

Input variables	Output variables
Total liabilities to assets ratio	Returns on net assets (ROE)
Total assets value	Significant business revenues
Total liability	Corporate growth ratio
Ownership interest	Liquid asset turnover ratio
Returns to scale in manufacturing	

$$a_i = \int_0^T [\lambda_i(x) + \nu_i(x)]\, dx$$

$$\tau = t - kT$$

Similarly, We Express

$$\int_0^t \nu_i(x) e^{\varphi_i(x)} dx = \sum_{l=1}^{k} \int_{(l-1)T}^{lT} \nu_i(x) e^{\varphi_i(x)} dx + \int_{kT}^{t} \nu_i(x) e^{\varphi_i(x)} dx$$

and this gives us

$$p_{0i}(t) = e^{-\varphi_i(\tau)} \left[\frac{b_i}{e^a - 1} + \int_0^\tau \nu_i(x) e^{\varphi_i(x)} dx \right] + e^{-ka-\varphi_i(\tau)} \left[\alpha_i - \frac{b_i}{e^a - 1} \right]$$

In This Case

$$b_i = \int_0^T \nu_i(x) e^{\varphi_i(x)} dx$$

3.1 Econometric Model

It is possible to assess the decreased energy efficiency intensity of GDP by looking at energy efficiency (Wang et al., 2022). It is used to calculate the energy efficiency of micro-entities, and the present research examines how ESG performance and digital finance may be utilized to lower financial resources required while increasing the efficiency with which those resources are allocated to other uses. The DEA-BCC model takes into account varying returns to scale in manufacturing and incorporates a large number of input and output indicators. Returns on net assets (ROE), significant business revenues, corporate growth ratio, and liquid asset turnover ratio are among the output indicators, with total liabilities to assets ratio, total assets value, total liability, and ownership interest being some of the input indicators.

Consider the following scenario: you have a group of n decision-making units (DMU). DEA-BCC is a model of corporate finance efficiency developed by Banker et al. (1984). It is characterized as follows: a minimum number of enterprises in emerging and developing markets. As a result, we primarily refer to the indicators used in previous studies in order to explain the selection of input/output variables in the scientific research phases.

Table 1 shows the descriptive statistics of significant important factors that are pertinent to this discussion. This paper investigates the effects of environmental, social, and governance (ESG) performance, various forms of digital finance, and the interacting terms of both ESG performance and digital finance on corporate financing efficiency by utilizing the above-mentioned variables.

TABLE 2 | Robustness test results using GMM panel data analysis.

Variable	AAA ~ A	BBB ~ B	CCC ~ C
ESG_{it}	1.0496***	0.5679***	0.4870***
DF_{it}	(0.4705)	(0.0894)	(0.2760)
age_{it}	0.0067***	0.5260***	0.3379***
roa_{it}	(0.0003)	(0.0981)	(0.0760)
Lev_{it}	−1.1943***	−0.1058***	−0.0935***
Control Variables	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes

*Notes; ***, **, and * refer to the significance at the 1, 5, and 10% significance levels, the values in parenthesis are the standard errors.*

TABLE 3 | Descriptive Statists.

Variables	Mean	Std. Dev	Min	Max
ESG_{it}	1.0496***	0.5679***	0.4870***	0.3379***
DF_{it}	−0.4705**	−0.0894**	−0.276*	1.0496***
age_{it}	0.0067***	0.5260***	0.3379***	−0.0145**
roa_{it}	−0.0003**	−0.0981*	−0.076**	−0.0003*
Lev_{it}	−0.074*	−0.0145**	−0.0132**	−0.0894*

*Notes; ***, **, and * refer to the significance at the 1, 5, and 10% significance levels, the values in parenthesis are the standard errors.*

Considering this scenario: We have a group of n decision-making units (DMU). If and only if a DMU's system efficiency is one, it is efficient. DEA-BCC is a model of corporate finance efficiency developed by (Charnes et al., 1994).

$$\text{CEF} = c + \alpha 1\text{ESGit} + \alpha 2\text{xit} + \alpha 3\text{ESGit xit} + \beta 1\text{sizeit} + \beta 2\text{levit} + \beta 3\text{roait} + \beta 4\text{gsit} + \beta 5\text{coit} + \beta 6\text{ageit} +$$

It is possible to assess the decreased energy efficiency intensity of GDP by looking at energy efficiency. It is used to calculate the energy efficiency of micro-entities, and the present research examines how ESG performance and digital finance may be use to lower the financial resources required while increasing the efficiency with which those resources are allocated to other uses. It is characterized that a minimum number of enterprises in emerging and developing markets have positive effect on financial performance.

At the 1% level of significance, all ESG performances have statistically significant effects on financial efficiency of business. Reduce information asymmetry in the stock market have negative effects while enhancing market information value will lead to improve the efficiency of financial resources. In accordance with research by Iqbal et al. (2021) and Zhang et al. (2021). ESG disclosure decreases the cost of corporate debt financing and increases the financial flexibility of the firm. In addition to the previous findings, (Iqbal et al., 2021), and (Zhang et al., 2021), have found that ESG performance has positive effects on corporate finance efficiency as well as on other factors. All of the overall digital finance indices, as well as the digitalization

TABLE 4 | Econometric analysis.

Variables	(PMG)	(PMG)	(MG)	(MG)	(DFE)	(DFE)
	ECT	SR	ECT	SR	ECT	SR
ESG_{it}	–	–0.0857***	–	–0.358***	–	–0.0578***
		(0.0325)		(0.0745)		(0.0396)
DF_{it}	–	0.524	–	0.589	–	0.252***
		(0.485)		(0.425)		(0.0554)
age_{it}	–	–2.658**	–	–2.689***	–	–0.487***
		(0.628)		(0.628)		(0.0857)
roa_{it}	–	0.358***	–	0.854***	–	0.125*
		(0.0589)		(0.265)		(0.0956)
Lev_{it}	–	0.0584	–	–0.0878	–	0.0369
		(0.254)		(0.395)		(0.0625)
	(0.547)		(6.854)		(0.584)	
Constant	–	–0.0325	–	0.748**	–	0.221*
		(0.0332)		(0.475)		(0.0652)
Hausman test	2.83 (0.5867)	–	–	–	24.63 (0.0000)	–
Observations	300	300	300	300		

level, coverage width, and usage depth of digital finance are found to be positively linked with corporate financing efficiency at the one percent level of significance (Yao et al., 2021). Digital finance coverage width has a greater positive impact than digital finance digitalization and utilization depth, and this is especially true for small businesses.

As demonstrated in **Table 2**, all of the results obtained by GMM panel data analysis exhibit a high degree of robustness. Furthermore, ESG performance in the AAA, AA, and A ratings has a much greater positive impact on corporate finance efficiency than ESG performance in the BBBB and CCCC ratings. Across the board, at the 1% level of significance, the entire indices of digital finance demonstrate gradually increasing effects on corporate financing efficiency, with a decline from AAA to C.

As shown in **Table 3**; when the BCC model is used to calculate corporate finance efficiency, the mean is 0.9162 and the standard deviation is 0.0489, suggesting that corporate finance efficiency is both greater and less variable. Companies' ESG performance has a standard deviation of 1.1755, indicating that the majority of businesses have a higher ESG performance and a larger time-varying trend than the average. The mean and standard deviations of corporate digital finance indices, as well as their digitalization degree, coverage width, and usage depth, all exhibit a stronger time-varying trend between 2013 and 2019. In order to examine robustness further, this article separates the firm samples into three sub-samples based on the ESG credit rating level: AAAA, BBBB, and CCCC.

The US crude oil firm's energy savings and greenhouse gas reduction possibilities was also studied by (Aisaiti et al., 2019). In the meantime, air emission abatement average costs have received a lot of attention recently. For instance, (Majumder et al., 2015), implemented ECSCs under both the Energy Environmental Damage Relationships and also to calculate poor air quality tax exemptions for China's mining and smelting and cement sectors. According to Ma et al., China's nitrogen sector has the ability to reduce air pollution (Barth et al., 2021) that 1) China's energy consumption is approximately 1 that of the United States—Asia's electricity demand in 2015 was just 5% of the 16 MWh per capita consumed in the world (Konopik, et al., 2022). China's per-capita power consumption is only about one that of the U.S., how frugal its multifamily housing sectors. Because multifamily housing power consumption has not yet peaked, it seems that both will rise in tandem with income until major progress is made in end-use energy efficiency. BP's Energy Outlook, for example, anticipates an 80 percent growth in power consumption by 2040, which is consistent with other energy predictions.

Since 1980, when the Chinese economy grew by 10.5 percent per year while energy consumption increased by 6% annually. There has been an energy–economic correlation of 0.857. Between 4 and 2.24 tonnes per RMB 11,000 ($1567, where 1 US dollar = RMB 6.36) of GDP, China's energy intensity decreased by an average of 3.91 percent each year (Zhou and Wang, 2019). It is estimated that 58.64 billion tonnes of coal equivalent (tce) were saved by the Chinese industries over this time period. The Integrated National Energy and Climate Action Plan (NECAP) (Ramsey et al., 2017), the memorandum forwarded by the Chinese government to the European Commission to illustrate how to meet the 2050 goals for energy efficiency and develop economic objectives for the strategic initiatives state implementation strategy. The text specifies a goal of 4 Mtoe for residential structures, which equates to 43 TWh. While this goal has been set, no information is provided as to how many properties will be refurbished, what types will be upgraded, or what initiatives will take place in order to achieve.

In addition, by drawing comparisons with the Singapore this study puts China's accomplishments into perspective. For a variety of reasons, this juxtaposition is helpful: Since its inception, the Singapore has maintained stringent environmental restrictions to address climate change by limiting traditional pollutants in the atmosphere derived from fossil-fired electricity generation (Sirota et al., 2008). Because it makes use of both the DEA's ability to handle many interdependencies as well as the regression method's capacity

to control a link between efficiency (or lack thereof) and the uncontrolled factors, this comprehensive strategy has been shown to yield trustworthy conclusions (**Table 4**). Energy efficiency has been examined using this combination of DEA and regression analysis in the current research. Since environmental factors in the area are widely varied, this might create some issues since HDD values are part of the world. In contrast, a linear association value of 0.80 has been calculated between the nation's HDDs and total household energy usage for the decade 1990–2015. Other research has likewise shown this to be the case (Stulz, 1996).

Individual depositors' information is needed in order to be linked to accessible panel information in the next phase of the process. The condition characterized techniques in this research are presented next and are built on earlier studies (Yang et al., 2021). The first step is to match up businesses from different years. The first step is to match the company ID. The company name is used unless the firm ID can be verified. Using the corporate participant and geographical number (4 digits) for verification. If the company name can always be confirmed, there are two ways to link the lawful combatant to the area code: the region code is used. The final seven characters are used for the establishment year and personal details. If it doesn't work, the starting year, area code (6 numbers), functional programming (3 digits), and primary goods are used to attempt to find the right match. Finally, the values that are not available for certain years are figured out. In certain years (such as 2003 and 2008), the overall economic growth, manufacturing economic benefit, and intermediate supply are completed in certain years. The total economic output value is the sum of commercial additional benefits and preliminary inputs less the value of additional tax payments. Prices have now reached their lowest point (Yu et al., 2020a). The depreciation of economic value creation, total capital equipment, deterioration, intermediary supply, and net capital equipment are computed. By using the company's own measure of inflation of industrial code review usefulness in each sector and the permanent portfolio management consumer price of each area. The fourth step is to use the accounting system technique to compute the significant industry and capital stock. Finally, the anomalies are culled from the data set. For aggregate output, transitional supply, productive capacity, and economic benefit, and a number of somewhere around eight workers, incomplete parameters or non-positive values are eliminated. Panel data for each company is now available.

4 DISCUSSION

All of the ESG findings have a significant impact on the efficiency of corporate financing. Corporate financing efficiency is increased by the complete indices of digital finance at the 1% level of significance. The interaction terms between ESG performance and digital finance, on the other hand, are reduced at the 1% level of significance. On the obtained basis, we search for the optimal solution. To do this, we formulate the problem in a general form. We define n which the number of users of the resources is. In this case, the load l_i where $i = 1...n$ reflects the externalities of each user (Rădulescu et al., 2019). We write an expression for the vector: $\bar{L} = (l_1, l_2, ..., l_n)$. We denote the total load as $L^* = \sum_{i=1}^{n} l_i$. We introduce the weighted average variable costs U_i, and the dependence $g_i(l_i)$ of the revenue of each user. Due to the limited capacity of the shared resource, starting from $\bar{L} > \bar{L}_R$, the profitability drops. This corresponds to the fulfillment of the condition $g_i{}'(l_i) < 0$. Moreover, due to the negative impact of the externalities of the specified n users, the second derivative is subject to the condition $g''_i(l_i) < 0$.Then the profit of the $i-$ user is

$$R_i = l_i\, g(l_1 + l_2 + ... + l_n) - U_i\, l_i = l_i\, g_i(L) - U_i\, l_i$$

Based on the Nash equilibrium principle, there is a value l_i^* for $i = 1...n$, which R_i reaches a maximum for any components of $\bar{L}$: $\bar{L}_i^*(l_1^*, l_2^*, ..., l_{i-1}^*, l_{i+1}^*, ..., l_n^*)$.

We find the extremum points from the conditions for the calculation: $\frac{\partial R_i}{\partial l_i} = 0$, at $i = 1...n$. Denoting the sum as $l_{-i}^* = \sum_{k \neq i} l_k^*$, we get $g(l_i + l_{-i}^*) + l_i g'(l_i + l_{-i}^*) - U = 0$

For $i = 1...n$, which gives us the desired value of $L^* = n\frac{U - g(L^*)}{g'(L^*)}$.

Consequently, the extremum is reached at $L_0 = \frac{U - g(L_0)}{g'(L_0)}$. Since the condition $n > 1$ is satisfied, it follows that $L^* > L_0$ (Yin et al., 2021) (Konopik et al., 2022). This proves that the obtained results meet the balance conditions and minimize the negative externalities. This research examines how digital finance and environmental, social, and governance (ESG) performance affect corporate financing efficiency using the DEA-BCC model and panel data analysis. Sustainable development and profitability, as well as increased social responsibility and corporate governance performance, are all indicators of strong ESG performance, which serves to protect the interests of all stakeholders.

According to (Wang et al., 2020), higher ESG performance reflects stakeholders' information needs, lowers financing costs, increases cash flows and continuous funds input and output efficiency, and promotes corporate financing efficiency. Using the 1% level of significance, the comprehensive indices, digitalization level indices, coverage width and usage depth indicators of digital inclusive finance all improve corporate financing efficiency, with coverage width indexes having a stronger positive effect than usage depth indicators and digitization level indicators. Furthermore, at the 1% level of significance, digital finance has a negative influence on the positive effect of ESG performance on the efficiency of corporate financial management. Good ESG practices should therefore be incorporated into corporate strategy in light of the rapid growth of digital finance in order to increase corporate financing efficiency while also sending a signal to stakeholders in the competitive finance market, especially given the rapid growth of digital finance.

5 CONCLUSION

Human energy consumption is increasing in lockstep with the digital economy's rapid growth. As a result of their high energy consumption, they have gotten a lot of attention from society in terms of energy conservation and emission reduction. As a result, enhancing the digital economy's energy efficiency has become a key study priority. In order to achieve this goal, researchers are working

to develop effective energy efficiency measurement approaches and measures. This paper has obtained an analytical solution in quadrature's scalable to each possible system modeling administrative decision-making within a region or a megacity. Using the superposition of the obtained solutions with weights corresponding to the initial decomposition, it becomes possible to get an integrated dependency, which is the basis for further calculation. Correspondingly, we formalize the resources of the megacity in the form of a set of structural subdivisions with limited bandwidth and a bunch of business units of users. For these resources, we will consider externalities in the form of impact on the ecological situation. We introduce the functions of the negative effect of users on the environment and the dependence of their profits on the costs of preserving the environment. Since, in this case, a whole set of solutions is obtained in which the balance of interests is achieved, we correspond each of them with the seasonality function of the resource loading. Based on the dependence of the environmental costs, we convert the calculation results into recommendations for administrative regulation necessary for the administration of the megacity to take decisions.

Technical recommendations are an important component of actions aimed at increasing energy efficiency. To promote the cause of energy conservation from a technical standpoint, stimulants and regulations promoting the adoption of the best available and efficient technologies, as well as better energy auditing procedures, are required. Consumer behavior has also been highlighted as a significant aspect in obtaining efficient energy use, according to recent study, and technology intervention has been identified as a crucial enabler for achieving such efficiency. It Works has been presented, which builds on the use of technology to change customer behavior in connection to energy efficiency.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

Conceptualization, SEB and SMS; methodology, IVK; software, EDP; validation, DVD, ABM, and LOA; Results, SUN and editing, AEK. All authors have read and agreed to the published version of the manuscript.

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Role of Green Financing and Eco-Innovation for Energy Efficiency in Developed Countries: Contextual Evidence for Pre- and Post-COVID-19 Era

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Following the environmental concerns such as global warming, climate change, and environmental degradation, scholars and policymakers discovered energy utilization as the key factor in these issues. Therefore, economies are paying more attention to green finance and eco-innovation to reduce energy usage and enhance energy efficiency. The prime objective of this study is to explore whether the mentioned variables exhibit any influence on the energy efficiency target achievement. In this sense, the current study explores the association of green finance and eco-innovation with energy intensity in the group of seven economies from 1990 to 2020. By using panel data approaches, this study employs diagnostic tests that confirm the heterogeneous slopes and the existence of panel cross-section dependence. Also, the cointegration tests validate the existence of a long-run equilibrium relationship between the variables. Based on the asymmetric distribution of the data, this study employs the method of moments quantile regression. The empirical results reveal that green finance and eco-innovation significantly reduce energy intensity across the selected quantiles. Control variables such as urban growth and trade openness also adversely affect energy intensity. However, economic growth is the only significant factor that enhances energy intensity. The results are robust as validated by the panel quantile regression and the Granger panel heterogenous causality test. Based on the findings, this study recommends that green finance be promoted and environmental-related technology innovation be encouraged to achieve the goal of energy efficiency in developed economies. This study also provides additional policies appropriate for environmental recovery.

Keywords: energy intensity, green finance, eco-innovation, urban growth, trade openness, method of moment quantile regression

1 INTRODUCTION

Extenuating climatic adversaries and achieving sustainable growth are prerequisites for every country's environmental and economic development worldwide. Though, the global pandemic has affected several countries and impacted the economic activities of the world. In retrospect, energy efficiency enhancements were quite slow, and Covid 19 has added an extra layer of ambiguity. The investments besides businesses were delayed and triggered market behavior changes that have impacted the progress of energy efficiency worldwide (Altarhouni et al., 2021). However, the economies are emerging globally, and revolution still has a long way to go in the future (International Energy Agency, 2020). Energy efficiency has enormous potential in accelerating sustainable economic development and vindicating pollution concerns besides promoting renewable energy consumption for a clean and green environment (Samour et al., 2022). Besides, eco-innovation and green financing sustenance create green business opportunities that support sustainable growth and development. According to Forbes, the United Kingdom, France, and Germany rank in the top 10 on the Environmental Performance Index, whereas Japan, Canada, and Italy ranked as average performers, and the United States is the poorest in terms of the level of green policies and environmental protection (EPI, 2022). The climatic trends have been changing due to extra-human activities. Attributable to IPCC (2014), world temperature is expected to rise by 2^0 to 4.7^0 Fahrenheit by the year 2100. Therefore, good governance, environmental regulation, and policy implementation could be beneficial in enhancing environmental quality (Habibullah et al., 2022).

Green financing helps boost energy efficiency and endorse environmental quality in challenging times. The association between green finance and energy intensity is usually negative, showing that green financing improves energy efficiency. Green finance provides green credits for projects for a better and sustainable environment (Qashou et al., 2022). It is sustainable in resource-abundant countries, where there is increasing economic dependence that supports energy efficiency optimization, such as developed economies. Liu et al. (2021a), Liu et al. (2021), and Tu and Rasoulinezhad (2021) reasoned that green financing can be highly operative and attractive in improving energy efficiency. Moreover, the group of seven nations has established strategic policies for green financial market development, whereas there are not any specific studies on eco-innovation and energy intensity because it is a non-debatable concept to date. However, in the case of Indonesia, Bahzar (2019) scrutinized the effect of eco-innovation on energy efficiency in their educational divisions. The empirical outcomes described the positive and constructive impact of eco-innovation on energy efficiency. The increasing eco-innovation in a country has positive and essential conservational benefits that optimize growth potential and increase economic savings and sustainability.

The study aims to investigate the influence of green finance and eco-innovation on energy efficiency in the group of seven developed economies during 1990–2020. In order to accomplish this, environmental taxes as a proxy of green finance, energy intensity, and a factor of energy efficiency are employed. Eco-innovation and energy intensity are not much-discussed factors in the existing literature. This is obtained in two econometric models explained in **Section 3**. Model 1 examines environmental taxes on energy intensity, and in Model 2, we corroborate the impact of eco-innovation on energy intensity. It is attributable to less researched and discussed factors, and the linkage must be deeply assessed in G7 economies; therefore, the present study aims to scrutinize this as a new input for researchers and policymakers because G7 urges to invest in vulnerable communities of the world to support them from the crisis.

The foremost research objective is to evaluate the causal association of environmental taxes on energy intensity in Model 1. Other explanatory variables include economic growth, urbanization or urban growth, and trade openness as control variables on energy intensity. Trade openness, GDP, and urbanization substantially influence energy consumption and efficiency. The second objective is to assess the causal effect of eco-innovation on energy intensity in Model 2 with other explanatory variables. These are the control variables in both econometric models. The estimates of both models are obtained by employing panel cointegration techniques to examine long-run correlations of variables, quantile regressions (MMQR), and Dumitrescu–Hurlin panel causality analysis to inspect the causal associations among different study variable pairs.

The motivation of the study lies in inspecting the energy efficiency determinants and their causal connection in the G7 economies. The G7 countries are developed nations that lead the world and significantly influence global GDP and trade activities. Hence, the present study is beneficial in evaluating energy efficiency. After all, the desired countries have not sufficiently invested in low carbon technologies since the COVID pandemic though they always have encouraged renewable green energies over fossil energies. The countries include Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. The G7 group is the biggest carbon emitter in the world. Additionally, green finance is highly effective in developed resource-abundant economies, and eco-innovation provides sustainable environment advantages that support sustainable development. Therefore, aspects have incentivized the authors to extend the debate on exploring energy intensity through eco-innovation and green finance in seven advanced western economies of the world.

The originality of the study is presented by the following contributions:

To the best of the author's knowledge, the study contributes to the literature in scrutinizing the role of green finance along with eco-innovation on energy efficiency for the first time. Only a limited number of studies considered and debated energy intensity areas. Hence, we use three main variables in the models, environmental taxes, eco-innovation, and energy intensity for the case of G7 economies of the world. The purpose of selecting the sample countries is that they are the best performing advanced economies with approximately

32 percent of the world's GDP. In addition, G7 countries have an environmental tax to GDP ratio from 0.6% to 2.5%. The increasing implementation of environmental taxes and eco-innovation by G7 economies will increase clean and green energy usage, and organizations will adopt it, leading to environmental welfare. Second, they infused billions of dollars in fossil fuel energy instead of clean green energy since the arrival of the COVID pandemic despite their green promises (Laville, 2021). Therefore, it is quite essential to analyze the role of environmental taxes, eco-innovation, and energy intensity and their connotation in this specific group of economies in two modifications in contributing to the academic and empirical literature. Second, the study also undertakes the influence of urban growth, economic growth, and trade openness on energy efficiency because GDP, trade, and urbanization have significantly affected energy consumption. In the existing literature, none of the studies explored all these factors over energy intensity, specifically in the post-COVID perspective. However, some studies have mentioned the substantial effect of the variables in a few countries (Lv et al., 2019; Peng and Zheng, 2021; Chen et al., 2022). Hence, the present study contributes to the literature by examining the influence of the said aspects by employing novel econometric techniques such as the method of moments quantile regressions, which is a more powerful technique than the panel quantile regression as it provides empirical estimates at a specific scale and location of the quantile, and the causality analysis tests for assessing causal linkage between eco-innovation, green financing, and energy efficiency in G7 economies considering the Covid 19 era. The present research is a new input in evaluating the multiple variables on energy intensity which is a less investigated and intricate concept. Further, the techniques provide efficient and reliable results. They expand the present debate besides encouraging future research by considering other relevant factors and countries for empirical evidence.

Section 2 provides brief literature reviews of under consideration variables. **Section 3** demonstrates the data assembling, model, and methodology of the study. **Section 4** documents the results and their discussions. **Section 5** presents conclusions and policy implications.

2 LITERATURE REVIEW

An expanded review of prevailing literature on variables under consideration is mentioned in the upcoming subcategories. There are limited research studies concerning green finance and eco-innovation on energy intensity and other explanatory variables in post-COVID years to date. Therefore, the studies cited below cover the pre- and post-COVID perspectives (years) for the understanding of under consideration factors. However, in this segment, a brief description of green financing and eco-innovation is presented initially. After that point, the nexus between intensity and green finance and energy intensity and eco-innovation are elaborated with a few related pieces of evidence from existing literature that might elucidate the associations more deeply. Later, exclusive connotations from the existing literature between gross domestic product, urban growth, and trade openness on energy intensity are mentioned.

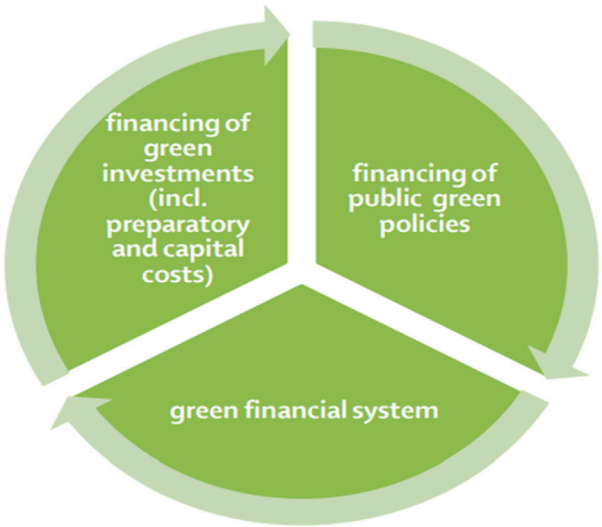

FIGURE 1 | Composition of green finance. Source: Lindenberg (2014).

In the literature, there is no exact definition of "green finance." However, according to the UN program for the environment, green financing refers to increasing the finance for sustainable development programs. It provides credits for projects for a better environment. Some interchangeably refer to green finance as green investments, but it is a broader component than investments. In the banking sector, some refer to it as financial services and products that promote sustainable environment-related investments, low-carbon technologies, and businesses, among others (Lindenberg, 2014). Additionally, the "green financing" progresses energy efficiency in the countries with substantial resource abundance, increasing economic dependence that supports energy efficiency optimization (Peng and Zheng, 2021). In **Figure 1**, the composition of green finance is demonstrated, which illustrates a clear definition of green finance. Zhao et al. (2022) proposed green financing as a new policy for environmental investment. They played a substantial role in promoting renewable energy investments required for clean and green energy (Li et al., 2022; Madaleno et al., 2022). Green financing policies are essential in transforming the economy and encouraging a green environment domestically and globally (Volz, 2018; Mumtaz and Smith, 2019).

A certain business approach gives lifelong product sustainability and encourages small and medium extent enterprises or SMEs (UN Environment Program, 2022). It is a substantial goal toward sustainable development that limits production modes. In general, it provides constructive environmental benefits and economical savings besides promoting social and organizational sustainable competitiveness (Carrillo-Hermosilla et al., 2009). Energy

intensity is a measure of energy that evaluates the efficiency of energy in an economy (Moyo et al., 2021; Samour and Pata, 2022; Shahzad et al., 2022). In the initial stages of economic development, an increase in energy intensity is usually expected due to the abundance of energy-intensive activities in the economy (Martinez et al., 2019). Certain factors impact the intensity or efficiency of energy. Below are some factors under consideration and their underlying linkage.

2.1 Energy Intensity and Green Finance Nexus

Energy intensity is a reciprocal of energy efficiency, which means that if energy intensity is reduced, it will be known as energy efficiency improvement. Liu et al. (2022) explored the role of different financing techniques on energy efficiency in the seven emerging nations. The empirical findings depicted that green financing is more powerful and supportive in enhancing energy efficiency. A green bond (green financing) is an essential tool for boosting energy efficiency and improving environmental quality in challenging times such as COVID-19. Azhgaliyeva et al. (2020) suggested that green bonds aid in promoting green finance and energy efficiency. Tu and Rasoulinezhad (2021) revealed that green bonds and regulatory quality positively influence the energy efficiency in 37 OECD members from the post-COVID time. The general findings showed that green bonds or green financing significantly improve energy efficiency. Additionally, He et al. (2021) analyzed the short- and long-run impacts of environmental taxes on the energy efficiency of OECD economies from 1995 to 2016. The results demonstrated that environmental taxes enhance energy efficiency in the long run. The manuscript is substantial in understanding the impact mechanisms related to environmental taxes on energy intensity. In another novel study of OECD economies from 1994 to 2018, Bashir et al. (2021) examined that green financing endorses energy intensity in those economies. The findings depicted those environmental taxes (green finance) that aid in controlling energy consumption and environmentally innovative technologies in the country. In the same direction, Rafique et al. (2022) concluded that environmental taxation reduces the ecological footprint in developed economies. Liu et al. (2021) professed that green financing is necessary to improve energy efficiency by 2030 (in the long run) in the United States. Rasoulinezhad and Taghizadeh-Hesary (2022) argued that green financing is an essential tool for encouraging green energy-related projects to promote energy efficiency that significantly mitigates carbon emissions. Peng and Zheng (2021) demonstrated that green finance has a stronger impact on energy efficiency and substantially enhances energy efficiency. The development of green technologies and innovation further enhances the efficiency of energy. Liu et al. (2021a) argued that green financing through renewable energy can be highly effective in enhancing and promoting energy efficiency. Zhou et al. (2022) documented the negative association of environmental taxes on the energy intensity of firms.

2.2 Energy Intensity and Eco-Innovation Nexus

Gerstlbergeret al. (2014) observed that the topic of product innovation and energy efficiency has been less researched and is complicated. Bahzar (2019) analyzed the influence of eco-innovation on energy efficiency in the educational sectors in Indonesia. The results depicted the positive and constructive impact of eco-innovation on energy efficiency. Energy efficiency is observed as an important aim for mitigating environmental concerns. Hille and Lambernd (2020) examined the influence of eco-innovation and government expenses in South Korea from 2002 to 2017. The empirical findings showed a strong influence of eco-innovation since 2009, but there has been no such improvement observed in the total energy intensity since then. Additionally, Wurlod and Noailly (2018) examined the negative relationship between green innovation and energy intensity in the case of OECD economies.

2.3 Gross Domestic Product Urban Growth and Trade Openness on Energy Intensity

Chen et al. (2022) scrutinized the influence of Gross domestic product on energy intensity in the case of China. The empirical outcomes depicted negative associations between economic growth and energy intensity attributable to the inclusion of control variables, and economic growth lessens the energy intensity. Further, the impact is more noticeable than any other variable under consideration. Hosan et al. (2022) explored the association between economic growth and energy intensity in emerging countries. Energy intensity and sustainability have an inverse relationship with the sustainable growth of the economy (GDP). Emir and Bekun (2019) analyzed feedback causal association between energy intensity and economic growth in the case of Romania. Zhou et al. (2021) observed the sample of 21 developed economies. The empirical findings showed an inverse (negative) relationship between energy intensity and economic growth due to the inclusion of other development factors. However, it can be enhanced (reversed) with an increase in the consumption of renewable energy (Isiksal et al., 2019; Pata and Samour, 2022; Samour et al., 2022). Economic growth also has a decoupling effect on energy intensity (Zhang et al., 2022). Bayar and Gavriletea (2019) determined the positive impact of energy intensity and economic growth with a one-way directional association. Bataille and Melton (2017) found a positive relationship between energy intensity with economic growth (GDP), welfare, and employment level in Canada. Similarly, Adom et al. (2021) expressed the positive linkage between energy efficiency and economic growth.

Sadorsky (2013) explored the mixed effects of urban growth on energy intensity. Yan (2015) scrutinized that urban growth plays a substantial role in increasing energy intensity in China. In the same way, Lv et al. (2019) explored the negative association between urban growth and energy intensity in the cities of China, whether it is direct, indirect, or total. Lin and Zhu (2021) also analyzed a novel (new) type of urbanization effect on the cities of

TABLE 1 | Variable specification and data sources.

Variable	Specification	Data source
EIN	Energy intensity, TPES per capita	OECD Data statistics (2022)
GRF	Green finance is proxied as environmentally related taxes and measured as a % GDP	OECD Data statistics (2022)
ECIN	Patent applications, residents	World Bank (2022)
GDP	GDP measured as constant 2015 US$	World Bank (2022)
URG	Urban population	World Bank (2022)
TO	Trade openness as % of GDP	World Bank (2022)

China's energy intensity. The empirical outcomes depicted a heterogeneous impact among the variables. Chen and Zhou (2021) found a positive influence of urbanization on energy intensity, but with the insertion of institutional variables, it weakens with a certain threshold value. In an empirical study in the case of OECD economies, Zhu et al. (2021) demonstrated an inverted U-shaped curve with heterogeneous impacts of urban growth on energy intensity depending on the type of country. In contrast, Shah, Naqvi, and Anwar (2020) found a positive association between urbanization and energy intensity in Pakistan.

The impact and association of trade openness with energy intensity are heterogeneous. However, trade openness has a significant impact on energy intensity in Bangladesh, which is highest in the long run (Pan et al., 2019a, Pan et al., 2019b). In another innovative study, Samargandi (2019) showed that trade openness is one of the driving factors in eliminating energy intensity. The results demonstrated that renewable energy consumption and trade openness are substantial factors limiting energy intensity in OPEC economies. Shah, Naqvi, and Anwar (2020) found a negative impact of trade openness on energy intensity in Pakistan during 1980–2017. Adom (2015) determined asymmetric effects between trade openness and energy intensity in Nigeria. In China, trade openness is negatively related to energy intensity (Chen et al., 2022).

3 DATA AND METHODOLOGY

3.1 Data and Model Specification

Following the objectives and literature presented above, this study investigates the influence of various economic and financial indicators on energy intensity (EIN). Nonetheless, the energy intensity or energy efficiency is now the leading concern across the globe and particularly in the developed economies. Since the traditional energy sources (such as oil, natural gas, and coal) are depleting natural resources, shortage of which could harm transportation, industry, and many other sectors. Consequently, economies are focusing on the proportion of energy efficiency or intensity. Therefore, it is essential to analyze whether innovative factors such as green finance and eco-innovation could help achieve the target of energy efficiency. Specifically, this study tends to analyze the influence of green finance (GRF) and econ-innovation (ECIN) on EIN. In recent times, economies have been struggling to boost their green finance and enhance environmental-related innovation not only to curb environmental degradation but also to reduce energy usage, whereas the given literature does not provide clear evidence to identify the true impact of the said variables on EIN. In this sense, empirical investigation of such variables is required to establish appropriate policies to attain environmental and energy-related objectives. Furthermore, control variables indicating economic growth and captured *via* gross domestic growth (GDP), urban growth (URG) proxied *via* urban population, and trade openness (TO) are also added to analyze the nexus comprehensively. Because these variables are important factors of enhanced income level and encouraging economic activities, the energy demand significantly increases. Hence, it is critical to empirically analyze the influence of such variables on EIN for a comprehensive analysis of the said issue. Data for the said variables are obtained from various sources, covering the period of 1990–2020 for seven economies, including Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States. Specifications of the variables and data sources for each variable are given in **Table 1**.

The current study aims to comprehensively investigate the impact of GRF and ECIN on EIN. Therefore, this study constructed two separate models to provide robust association estimates. The two models are given as follows:

Model 1:

$$EIN_{it} = \alpha_1 + \beta_1 GRF_{it} + \beta_2 GDP_{it} + \beta_3 URG_{it} + \beta_4 TO_{it} + \varepsilon_{it} \quad (1)$$

Model 2:

$$EIN_{it} = \alpha_1 + \beta_1 ECIN_{it} + \beta_2 GDP_{it} + \beta_3 URG_{it} + \beta_4 TO_{it} + \varepsilon_{it} \quad (2)$$

From **Eqs 1**, **2**, $\alpha' s$ and $\beta' s$ are the intercept and slopes, whereas the cross-section and time series are denoted *via* "*i*" and "*t*" in the subscript. Moreover, ε indicates the random error term of the model.

3.2 Estimation Strategy

The empirical analysis portion of the present research begins with an evaluation of descriptive analysis and estimations of normality. In particular, the mean, median, and range (minimum and maximum) values that describe the complete dataset are examined. Furthermore, the standard deviation is evaluated to determine a variable's overall volatility. In addition, the normality of each variable under examination was evaluated. In other words, skewness and kurtosis reveal the breadth and height of distribution, respectively. Specifically, the range for each of these measurements is between −2 and +2 for skewness and

between −7 and +7 for kurtosis (Byrne, 2013). This research also employs a thorough test for normalcy, namely, the Jarque and Bera (1987) normality test, which treats the skewness and excess kurtosis concurrently and proposes that these components are equal to zero, replicating the null hypothesis. The typical formula of the aforementioned test is given as follows:

$$JB = \frac{N}{6}\left(S^2 + \frac{(K-3)^2}{4}\right). \tag{3}$$

After industrialization and international commerce, globalization expanded, despite variables that affect an economy's dependency on other nations. Specialization in particular commodities or services encourages other nations and territories that use them. This dependency is necessary to attain government-defined cultural, financial, social, technological, economic, environmental, and technological objectives and goals. Depending on such characteristics, a nation's economy may show similarities or differences in specific sectors compared to other countries' economies, causing slope heterogeneity and cross-section dependency issues. This research estimates panel data using slope heterogeneity and cross-sectional dependency. If slope heterogeneity and cross-section dependence are neglected, the econometric analysis may be unproductive (Le and Bao, 2020; Wei et al., 2022). Pesaran and Yamagata's (2008) slope coefficient heterogeneity (SCH) and Pesaran's (2004a) panel cross-section dependence (CD) diagnostic tests are utilized to evaluate two-panel data issues. The usual equation for estimating the SCH test is as follows:

$$\hat{\Delta}_{SCH} = \sqrt{N(2k)^{-1}}\left(N^{-1}\acute{S} - \mathrm{K}\right). \tag{4}$$

This test also examines the adjusted SCH, which may be calculated using the following method:

$$\hat{\Delta}_{ASCH} = \sqrt{N}\sqrt{\frac{T+1}{2K(T-K-1)}}\left(N^{-1}\acute{S} - 2\mathrm{K}\right). \tag{5}$$

The SCH test proposes that the slope coefficients are homogenous, whereas it accepts the alternative hypothesis only if the results are statistically significant.

Cross-section dependence may also provide biased econometric estimates if it prevails in data (Campello et al., 2019). In this scenario, Pesaran's (2004b) CD test is employed, expressed as follows:

$$\mathrm{CD}_{Test} = \frac{\sqrt{2T}}{[N(N-1)]^{1/2}}\sum_{i=1}^{N-1}\sum_{k=1+i}^{N} T_{ik}. \tag{6}$$

The proposed test assumes the presence of panel cross-section dependence in the selected economies. If estimations are statistically significant at the 1%, 5%, or 10% levels, the alternative hypothesis will be adopted.

Because the current research employs panel data that satisfy the property of SCH and CD, a second-generation unit root estimator is employed to address these issues. This research employs the Pesaran (2007) CIPS testing approach. Pesaran (2006) described cross-sectional dependency component modeling, where the unexplained cross-sectional means are examined. Pesaran (2007) adds mean and first difference lag cross-sections to Augmented Dickey–Fuller (ADF) regression. This method creates cross-sectional dependency even if the panel is unbalanced ($N > T$ or $N < T$). Quantifying ADF cross-section,

$$\Delta y_{i,t} = \theta_i + \beta_i^* y_{i,t-1} + d_0\bar{y}_{t-1} + d_1\Delta\bar{y}_t + \varepsilon_{it}, \tag{7}$$

where $\bar{y}_t$ is the mean of observations. In order to cope with serial correlation, the following initial lags of $\bar{y}_t$ and y_{it} may be inserted into the above equation:

$$\Delta y_{it} = \theta_i + \beta_i^* y_{i,t-1} + d_0\bar{y}_{t-1} + \sum_{j=0}^{n} d_{j+1}\Delta\bar{y}_{t-j} + \sum_{k=1}^{n} c_k\Delta y_{i,t-k} + \varepsilon_{it}. \tag{8}$$

CIPS (Pesaran, 2007) may be investigated across the G7 economies by averaging t-statistics for each cross-sectional unit (*CADFi*). The *CIPS* formula is given as follows:

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i. \tag{9}$$

CIPS assumed a time series unit root as the null hypothesis.

Because each variable is stationary, it is important to determine whether they have a long-run stable connection. This research employs two-panel cointegration methodologies, including Westerlund's (2005) variance ratio and Pedroni's (2004) cointegration test. The latter estimates the Modified Phillips–Perron, Phillips–Perron, and Augmented Dickey–Fuller tests. Both the experiments assume no long-run association between the parameters. Still, if the statistical results of these tests are significant at any of the 1%, 5%, or 10% levels, the proposition could be rejected that concludes the presence of cointegration between the variables.

The Jarque and Bera (1987) normality test illustrates the asymmetric distribution of the variables. Therefore, this study uses a novel approach that considers the issue of normality in data. Koenker and Bassett (1978) used panel quantile regression to calculate conditional variance and the mean dependent. Any kind of quantile regression works well with asymmetric or non-normal datasets (Shahzad et al., 2020; Hashmi et al., 2021; Iqbal et al., 2021; Shahzad et al., 2021; Akram et al., 2022). In response to this, Machado and Silva (2019) created a method of moment quantile regression (MMQR) approach. This approach studies quantile distributions and has recently been used in energy and environmental-related studies (Sarkodie and Strezov, 2019; Rehman et al., 2021; Yan et al., 2022). **Eq. 10** provides the location and scale variant $Q_y(\tau|R)$:

$$Y_{it} = \alpha_i + \beta R_{it} + (\gamma_i + \rho\acute{Z}_{it})\mu_{it}, \tag{10}$$

where the probability $p(\gamma_i + \rho Z'_{it} > 0)$ is considered as one. Besides, the estimated coefficients in the equation above are α, β, γ, and ρ, where the subscript "i" indicates the fixed effect represented by α_i and γ_i and $i = 1, 2, \ldots, n$. Furthermore, the characteristic component R is a k-vector, represented by Z, and the component ″6″ displays a distinctive variant:

$$Z_{\|} = Z_6(R),\ 6 = 1, 2, \ldots, k. \tag{11}$$

In **Eq. 11**, in terms of fixed "i" and "t" (time), R_{it} is identically and independently distributed, which is orthogonal to "i" and "t" (Machado and Silva, 2019). As a result, the reserves and the external components stabilize. Following the backdrop, the primary models of this study presented as **Eqs 1**, **2** could be transformed into the following MMQR regression form:

$$Q_y(\tau|R_{it}) = (\alpha_i + \gamma_i q(\tau)) + \beta R_{it} + \rho \acute{Z}_{it} q(\tau). \quad (12)$$

Here, **Eq. 12** indicates that R_{it} is a vector that collectively represents the independent variables, including the GRF, GDP, URG, TO in Model 1 and $ECIN$, GDP, URG, TO in Model 2, whereas the vector R_{it} also replicates Y_{it} as it captures the dependent variable EIN, which is also dependent on the quantile's position. All the selected variables are taken in the natural logarithmic form. Furthermore, the scalar coefficient, $-\alpha_i(\tau) \equiv \alpha_i + \gamma_i q(\tau)$, indicates the stable influence of τ quantiles on i. On the contrary, there is no influence of quantile on intercept. However, due to the variables' exogenous and temporal composition, other effects are subtle to adjust. In conclusion, q(τ) provides samples of the τ-the quantiles, which are considered as four in this specific study: 25th, 50th, 75th, and 90th. This study uses the following quantile equation:

$$min_q \sum_i \sum_t \theta_\tau \left(R_{it} - (\gamma_i + \rho \acute{Z}_{it})q\right), \quad (13)$$

where $\theta_\tau(A) = (\tau - 1)\ AI\{A \le 0\} + TAI\{A > 0\}$ reveals the check function.

In order to validate the empirical findings of the discussed approach, this study also utilizes the panel quantile regression, which could be translated into the following forms by altering **Eqs 1**, **2**, respectively:

$$Q_{EIN_{it}}(\theta|\alpha_i, \varphi_t, X_{it}) = \alpha_i + \varphi_t + \varphi_{1,\theta} GRF_{it} + \varphi_{2,\theta} GDP_{it} + \varphi_{3,\theta} URG_{it} + \varphi_{4,\theta} TO_{it} + \varepsilon_{it} \quad (14)$$

$$Q_{EIN_{it}}(\theta|\alpha_i, \varphi_t, X_{it}) = \alpha_i + \varphi_t + \varphi_{1,\theta} ECIN_{it} + \varphi_{2,\theta} GDP_{it} + \varphi_{3,\theta} URG_{it} + \varphi_{4,\theta} TO_{it} + \varepsilon_{it} \quad (15)$$

where θ in the subscript indicates the quantile of each specified variable.

This study also uses the Granger panel causality heterogeneity test proposed by Dumitrescu and Hurlin (2012) because the previous methods cannot establish a causal link between explanatory and dependent parameters. Despite an imbalanced panel (when T does not equal N), this approach provides efficient statistics, is more robust, and tackles the panel CD and SCH issues (Banday and Aneja, 2020).

4. RESULTS AND DISCUSSION

This segment of the manuscript deals with the results and their discussions with tables and respective models' graphical outcomes.

4.1 Descriptive Statistics

The average values are nearly the same as their median values with some points difference. The data spread or dispersion from the mean position of the variables is demonstrated through the standard deviations mentioned in **Table 2**. Data precision and symmetry are demonstrated with the help of skewness and kurtosis values. For symmetry of the distribution or skewness, the range is from −2 to +2, whereas the range from −7 to +7 shows the value of kurtosis or peaked distribution. The values of skewness and kurtosis lie in the mentioned range. Skewness is depicting positive with an approximately skewed distribution. Kurtosis describes the peak of the distribution. The probability values are also significant.

4.2 Slope Heterogeneity and Cross-Sectional Dependence

Tables 3, **4** denote the estimates of slope heterogeneity and cross-sectional dependence. Different countries under consideration across the panel have comparations or distinctions that may give ineffective and inconsistent results. For unbiased results, slope heterogeneity and cross-section dependence tests are employed in panel analysis. The slope heterogeneity of both models (1 and 2) has significant values at one percent of the level of significance. The estimates reject the null hypothesis at 1% that the variables are not statistically homogeneous in both econometric models. Later, after confirming heterogeneity, the inter-dependence in the cross-sectional analysis of variables is examined. The findings of cross-sectional dependence describe that variables are significant and reject the null hypothesis at a 1% level of significance, portraying that the information is codependent across the panel. The variables are correlated and attributable to the presence of unobserved factors, each affecting the other in the panel.

4.3 Unit Root Test

The codependence of variables and heterogeneity leads to the analysis of unit root for level I(0) and the first difference I(1). Panel unit root tests are advanced forms of conventional unit root tests named Augmented Dickey–Fuller test. The panel unit root (Pesaran 2007) considers cross-sectional averages that were disregarded in conventional ADF unit root. At level, only energy intensity has a significant and negative value, whereas all the estimates are insignificant with negative values in **Table 5**. At first difference, all variables are significant with a 1% level of significance except for Urban growth is substantial at a 5% level of significance. In general, the results rejected the null hypothesis with negative values of coefficients demonstrating a higher occurrence of a unit root in the variables.

4.4 Cointegration Analysis

The cointegration analysis demonstrates the long-run association of the variables for a specific period in a time series (non-stationary) data. The unit root tests validate the presence of panel unit root in the information leading to examining the cointegration among the variables using Pedroni and Westerlund Cointegration tests. Pedroni cointegration analysis comprises three sets of tests, whereas the Westerlund cointegration test is based on the variance ratio of models (1 and 2) mentioned in **Table 6**. Both tests' null hypotheses display no cointegration in both models. The statistical estimates of Phillips–Perron and Augmented Dickey–Fuller test are significant in Model 1 and Model 2, with a 1% level of significance rejecting the hypothesis.

TABLE 2 | Descriptive statistics and normality check.

	EIN	*ECIN*	*GRF*	*GDP*	*URG*	*TO*
Mean	1.484429	10.28895	1.994816	28.71936	17.95291	48.73420
Median	1.382835	9.788806	2.167000	28.55584	17.77113	50.63172
Maximum	2.144754	12.86712	3.597000	30.62548	19.42876	88.43441
Minimum	0.841957	7.687997	0.719000	27.56247	16.86981	15.81031
Std. Dev.	0.380625	1.521035	0.763326	0.756052	0.675602	18.33408
Skewness	0.499617	0.375906	0.157903	1.086599	0.752704	0.031366
Kurtosis	1.961461	1.845179	2.245337	3.553008	2.724047	2.293297
Jarque–Bera	18.77985	17.16860	6.051133	45.46700	21.17926	4.551248
Probability	0.000084	0.000187	0.048530	0.000000	0.000025	0.102733
Observations	217	217	217	217	217	217

Note: the descriptive statistics are calculated based on log-transformed data.

TABLE 3 | Slope heterogeneity.

Slope heterogeneity test	Statistics
Model 1	
$\tilde{\Delta}$	19.621***
$\tilde{\Delta}^{Adjusted}$	21.848***
Model 2	
$\tilde{\Delta}$	19.979***
$\tilde{\Delta}^{Adjusted}$	22.247***

*Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.*

TABLE 4 | Cross-section dependence.

Cross-section dependence	
EIN	***GRF***
17.665***	12.843***
ECIN	***GDP***
3.491***	23.504***
URG	***TO***
23.936***	16.533***

*Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.*

TABLE 5 | Unit root testing (Pesaran, 2007).

Variables	Intercept and Trend	
	I(0)	**I(1)**
EIN	−3.190***	−5.984***
GRF	−1.459	−4.563***
ECIN	−2.176	−4.839***
GDP	−1.978	−4.127***
URG	−2.425	−2.879**
TO	−1.866	−3.966***

*Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.*

The results portray the existence of cointegration in the econometric models. The Westerlund test also rejects the null hypothesis at a 10% level of significance. The variance ratio confirms the existence of cointegration. The results validate the long-run relationship of variables. Green finance, economic growth, urban growth, and trade openness are correlated with energy intensity in Model 1. Eco-innovation, economic growth, urban growth, and trade openness are interrelated with energy intensity in Model 2.

TABLE 6 | Cointegration test.

Test	Statistics	*p*-value
Pedroni cointegration test		
Model 1		
Modified Phillips–Perron test	−0.2976	0.3830
Phillips–Perron test	−3.8696	0.0001
Augmented Dickey–Fuller test	−2.9183	0.0018
Model 2		
Modified Phillips–Perron test	−0.6004	0.2741
Phillips–Perron test	−5.2841***	0.0000
Augmented Dickey–Fuller test	−3.8831***	0.0001
Westerlund Cointegration Test		
Model 1		
Variance ratio	−1.4106*	0.0792
Model 2		
Variance ratio	−1.3883*	0.0825

*Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.*

4.5 Quantile Regression and Test for Robustness

In the authorization of long-run relationships above, the panel regressions, such as quantile regressions, are applied as a leeway of Ordinary least squares (linear regressions). The estimates of the method of moments quantile regressions (MMQR) are presented in **Tables 7**, **8** for Model 1 and Model 2, respectively.

In Model 1, green finance (GRF) is negatively and significantly associated with energy intensity (EIN) in all quantiles at a 1% level of significance. Economic growth (GDP) is significant and positively associated with energy intensity in all quantiles (Bayar and Gavriletea, 2019). Similarly, the coefficient of urban growth (URG) and trade openness (TO) is negative at a 1% significance level depicting an increase in these two variables (URG, TO), substantially decreasing energy intensity in G7 countries (Lv et al., 2019; Shah, Naqvi, and Anwar, 2020). In Model 2, all quantiles represent significant results except in the first quantile Q (0.25). Eco-innovation is negatively associated with energy intensity in approximately all quantiles (Wurlod and Noailly, 2018). The other variables, such as GDP, have a positive linkage,

TABLE 7 | Estimates of quantile regression–MMQR (Model 1).

<!—Col Count:7-->Variable	Location	Scale	Quantiles			
			$Q_{0.25}$	$Q_{0.50}$	$Q_{0.75}$	$Q_{0.90}$
GRF	−0.474*** [0.016]	−0.009*** [0.009]	−0.467*** [0.020]	−0.476*** [0.015]	−0.483*** [0.015]	−0.490*** [0.017]
GDP	0.589*** [0.099]	−0.089*** [0.059]	0.657*** [0.123]	0.576*** [0.096]	0.511*** [0.093]	0.446*** [0.108]
URG	−0.904*** [0.117]	0.143** [0.070]	−1.012*** [0.146]	−0.884*** [0.115]	−0.778*** [0.110]	−0.674*** [0.128]
TO	−0.004*** [0.001]	0.001* [0.001]	−0.005*** [0.001]	−0.004*** [0.001]	−0.003*** [0.001]	−0.002** [0.001]
Constant	1.945** [0.951]	0.089*** [0.569]	1.878 [1.180]	1.958** [0.924]	2.023** [0.894]	2.088** [1.044]

*Note: EIN is the dependent variable. Significance level is denoted by *** for 1%, ** for 5%, and * for 10%. The standard error is in the bracket.*

TABLE 8 | Estimates of quantile regression–MMQR (Model 2).

Variable	Location	Scale	Quantiles			
			$Q_{0.25}$	$Q_{0.50}$	$Q_{0.75}$	$Q_{0.90}$
ECIN	−0.196** [0.093]	−0.109** [0.046]	0.065 [0.149]	−0.179** [0.091]	−0.151** [0.071]	−0.239** [0.102]
GDP	0.946* [0.572]	0.364** [0.167]	0.608 [0.910]	0.956* [0.558]	1.327*** [0.431]	1.619*** [0.624]
URG	−0.916** [0.365]	−0.396* [0.205]	−0.549 [1.380]	−0.928* [0.545]	−1.33** [0.649]	−1.650* [0.944]
TO	−0.013*** [0.004]	−0.002** [0.001]	−0.001 [0.006]	−0.013** [0.005	−0.006** [0.003]	−0.008** [0.004]
Constant	−8.688*** [2.433]	−1.816* [1.084]	−7.004* [3.941]	−8.738*** [2.407]	−10.587*** [1.835]	−12.045*** [2.690]

*Note: EIN is the dependent variable. Significance level is denoted by *** for 1%, ** for 5%, and * for 10%. The standard error is in the bracket.*

TABLE 9 | Robustness test–quantile regression.

Variable	Model 1 quantiles				Model 2 quantiles			
	$Q_{0.25}$	$Q_{0.50}$	$Q_{0.75}$	$Q_{0.90}$	$Q_{0.25}$	$Q_{0.50}$	$Q_{0.75}$	$Q_{0.90}$
GRF	−0.454***	−0.421***	−0.501***	−0.513***	–	–	–	–
ECIN	–	–	–	–	0.076	−0.147**	−0.215**	−0.226***
GDP	0.681***	0.638***	0.285**	0.175**	0.850***	0.150	1.002**	0.595**
URG	−1.030***	−0.939***	−0.512***	−0.340***	−0.771**	0.376	−0.892	−0.316
TO	−0.004**	−0.003***	−0.003***	−0.001	−0.001	−0.002	−0.010**	−0.001
Constant	1.426	1.027	3.799***	3.832***	−10.071***	-8.058***	−8.293***	−7.126***

*Note: EIN is the dependent variable. Significance level is denoted by *** for 1%, ** for 5%, and * for 10%. The standard error is in the bracket.*

whereas URG and TO have negative associations with energy intensity.

Table 9 demonstrates the robustness of the MMQR. The robustness test is a goodness of fit test for examining the reliability and fitness of the model. The general results describe the goodness of fit of the MMQR (Models 1 and 2). In Model 1, all variables in all quantiles are robust with significant values. While in Model 2, nearly some quantiles depict significance and validate the robustness. Moreover, **Figures 2**, **3** show the graphical representation of quantiles of both models (1 and 2) with respective variables.

4.6 Dumitrescu–Hurlin Panel Causality

The Dumitrescu–Hurlin panel causality test governs the causal relationship among the study variable pairs. In **Table 10**, nearly all pairs have significant and causal associations. Pairs such as EIN $\nRightarrow$ GRF, ECIN $\nRightarrow$ EIN, EIN $\nRightarrow$ ECIN, GDP $\nRightarrow$ EIN, URG $\nRightarrow$ EIN, EIN $\nRightarrow$ URG, and TO $\nRightarrow$ EIN have significant outcomes displaying causal associations. Attributable to the estimates of energy intensity and green finance, these variables are found in one-way causal connection, while eco-innovation, and energy intensity have a bidirectional causal association; that is, eco-innovation causes a significant impact on energy intensity and vice versa. Economic growth and trade openness have one-way causality with energy intensity in the case of the group of seven developed countries. Lastly, urban growth is bidirectionally associated with energy intensity in G7 economies. The empirical findings of this study align with each variable's substantial influence on the intensity of energy. The countries must endorse promoting green and efficient technologies for sustainable development. The legislators need to focus on introducing eco-innovation that will minimize the energy usage per unit and further management policies in the selected panel economies.

4.7 Discussion

First, the correlation (long run) results of green finance on energy intensity are somehow comparable to the case of Doğan et al. (2022) that increasing environmental taxes (green finance) lessens the intensity of traditional energy usage. The causality runs from energy intensity to the green finance that enhances energy intensity influences the green finance or environmental taxes. Further, the negative relationship between taxes and

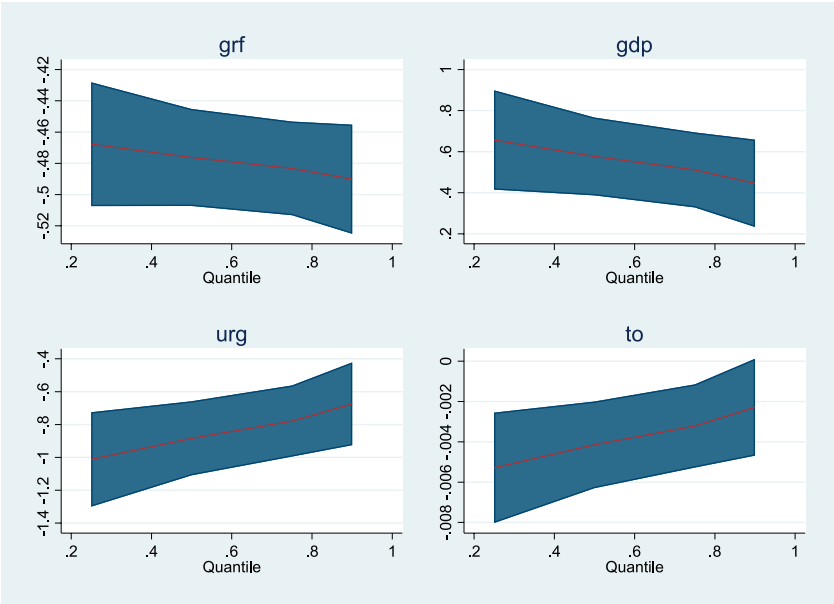

FIGURE 2 | Graphical presentation of quantile regression for Model 1.

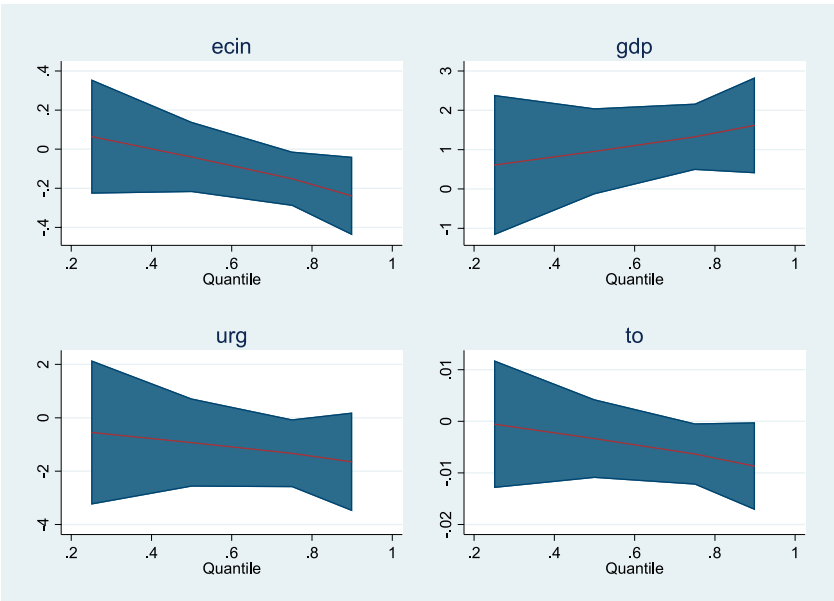

FIGURE 3 | Graphical presentation of quantile regression for Model 2.

energy intensity is consistent with the findings of Zhou et al. (2022) at the firm level. Second, the correlation between eco-innovation and energy intensity is also negative but with bidirectional causality that an increase in eco-innovation significantly affects energy intensity and *vice versa*. Wurlod and Noailly (2018) demonstrated that increasing green innovation or eco-innovation can be inversely linked with energy intensity, thereby reducing the energy intensity. Hence, the negative and significant effects of eco-innovation and energy intensity of the present study are reliable with the study (Wurlod and Noailly, 2018).

Third, the economic growth and energy intensity have a unidirectional but positive association running from gross domestic product to energy intensity. Economic growth and

TABLE 10 | Dumitrescu–Hurlin panel causality.

H_0	$Wald_{Stats}$	$\bar{Z}_{stats}$	*p*-valuep – value
EIN ⇏ GRF	13.5703***	12.6068	0.0000
GRF ⇏ EIN	3.24192	1.17352	0.2406
ECIN ⇏ EIN	6.75669***	5.06429	4.E-07
EIN ⇏ ECIN	4.43318**	2.49221	0.0127
GDP ⇏ EIN	8.43542***	6.92261	4.E-12
EIN ⇏ GDP	0.94535	−1.36874	0.1711
URG ⇏ EIN	8.00687***	6.44822	1.E-10
EIN ⇏ URG	3.76501*	1.75256	0.0797
TO ⇏ EIN	9.59982***	8.21159	2.E-16
EIN ⇏ TO	2.09384	−0.09739	0.9224

*Note: significance level is denoted by *** for 1%, ** for 5%, and * for 10%.*

energy intensity associations and causal linkage (Bayar and Gavriletea, 2019; Adom et al., 2021) have consistent findings, constructive and unidirectional. For the outcomes of urban growth and energy intensity, the present empirical findings depicted a negative association between urban growth and energy intensity with bidirectional causality. The developed countries are usually energy-intensive with significant but negatively associated energy intensity. Therefore, consistent with the study of Zhu et al. (2021), the findings of trade openness also have an inverse relationship with the one-way causal association. The results are somehow reliable (Shah, Naqvi, and Anwar, 2020; Chen et al., 2022).

In general, green finance and eco-innovation have significant effects with explanatory variables such as GDP, urban growth, and trade openness on developed economies. COVID-19 has affected most of the nations worldwide. The above empirical findings can be effective for researchers, academicians, and policymakers to re-evaluate economic, environmental, and energy-related policies and fulfill the country's requirements and support the betterment of the vulnerable economies for sustainable development.

5 CONCLUSION AND POLICY IMPLICATION

5.1 Conclusion

On the nexus between green finance and eco-innovation, a very limited number of studies are available in the prevailing literature with insufficient empirical evidence, especially considering the impact on energy intensity. Hence, the current study deliberately tries to fill the gap by examining the influence of green finance and eco-innovation on the energy intensity of the G7 countries from 1990 to 2020 (post-COVID 19 perspectives). The study uses novel variables such as environmental taxes (green finance) and eco-innovation along with GDP, urban growth, and trade openness to assess the connection. For analysis, the authors employed panel econometric approaches and tests for long-run causal relationships. The present study is, one way or another, reliable to the subsequent studies (Wurlod and Noailly, 2018; Adom et al., 2021; Zhu et al., 2021; Shah, Naqvi, and Anwar, 2020; Chen et al., 2022; Doğan et al., 2022; Zhou et al., 2022) concerning the above-mentioned factors. However, the study is novel in examining green financing and eco-innovation on energy efficiency in G7 developed economies simultaneously.

In the unit root test, Pesaran (2007) detected the strong existence of unit roots among the variables of developing seven economies. The panel cointegration (Pedroni and Westerlund) tests revealed long-run associations between the variables of both Models (1 and 2). Further, the quantile regressions and robustness test signified substantial and momentous results. Green finance (GRF) and eco-innovation (EIN) are negatively and significantly associated with energy intensity in approximately all quantiles in the tables. An increase in green financing and eco-innovation negatively impacts the intensity of the energy in G7 countries. The general robustness results describe the goodness of fit and reliability of the MMQR. Then, the causality analysis in **Table 10**, which evident unidirectional causal influence form energy intensity to green finance. The association between eco-innovation and energy intensity has a bidirectional causal association; eco-innovation causes a noteworthy influence on energy intensity. Moreover, the explanatory variables such as economic growth and trade openness have unidirectional causality with energy intensity in the case of the group of seven developed countries. Lastly, urban growth has a bidirectional connotation with energy intensity in G7 countries.

Since the COVID pandemic, the G7 economies, including Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States, have not sufficiently invested in low carbon energy-efficient technologies. However, they always have encouraged renewable green energies over fossil energies. Energy efficiency has enormous potential in accelerating sustainable economic development and vindicating environmental concerns. Green finance and eco-innovation have substantial effects on the intensity of energy besides the role of GDP, urban growth, and trade openness playing a substantial part in the case of developed economies. The pandemic has affected numerous countries around the world. The above precise and pragmatic findings can be effective for researchers, academicians, and policymakers to re-evaluate the present study by inserting other factors such as quality of the environment, institutional quality, and technological advancement for future research. It further increases the present debate in literature besides encouraging forthcoming exploration of other countries concerning present factors for empirical evidence that will help understand the concept for in-depth analysis.

5.2 Policy Implications and Future Recommendations

Based on the study's findings, the succeeding mentioned some relevant policy implications. Specifically, energy efficiency and intensity are key factors for sustainable development. The present study has a significant influence on certain variables that help promote energy intensity for sustainable development. Overall, each variable has a considerable influence on energy intensity. In order to encourage sustainable energy, countries must endorse promoting green and efficient technologies. Policymakers and

strategists need to focus on introducing eco-innovation by companies that will minimize the energy usage per unit and further management policies. A green bond, investment, or security verifier must be established to authorize them before issuing in the country. The third party attempts to authorize the bonds, securities, and investments and evaluate them as green by estimating the project's benefits. Market reform policies are also necessary to initiate sustainable technologies and innovations by specifying the characteristics of products, appliance standards, and so on. The developed countries need to advance energy and environment policies as they have done in the past that aid in fulfilling the country's requirements of promoting green finance and eco-innovation. In addition, developed nations must support vulnerable economies to improve sustainable development.

Additionally, they should strengthen the environmental protection system and enhance the environmental regulatory systems, such as the formulation of green and technological innovation capability policies, pollution control, and protection standards. Likewise, environmental regulations are essential tools that enhance environmental quality. These ensure that all living beings, either animals or humans in the ecosystem, are not harmed; besides, governments do not cause harm and implement laws and policies that protect the environment.

The study is constrained to a group of seven economies. Therefore, it is necessary to investigate the present influence of under consideration variables in another set of developed economies (replicated) to scrutinize and assess the concept more deeply as a part of the future scope. It will provide additional empirical evidence to researchers, practitioners, and energy strategists to revamp environmental and sustainable policies. Second, the influence of study variables would be different for developing countries. It will be substantial to expand the current research in developing nations for comparison. It would be useful for developing nations to evaluate the policies and implement them. The third restriction with the endorsement, energy intensity, and eco-innovation are less researched areas in empirical and academic literature. Energy is a broader concept, and its usage is important in our daily lives. The effect of environmental quality, technological innovation, and globalization can also be evaluated in the context of G7 countries. Therefore, it is recommended to inspect these factors with the inclusion of other relevant factors that help in the process of sustainable environment and development.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HW: concept, data, and theory. EW: literature review, preparing the draft, and analysis. DR: introduction, methodology, and software. MH-S: supervision, editing, data analysis, results, and discussion.

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Assessing the employees' efficiency and adaptive performance for sustainable human resource management practices and transactional leadership: HR-centric policies for post COVID-19 era

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The utilization of sustainable organizational human resource management (HRM) practices as predictors of adaptive performance has received little attention, despite the importance of adaptive performance in improving organizational efficiency. This study explores the relationship between HRM activities (training, performance appraisal, job enlargement, employee involvement, and work enrichment) and employees' adaptive performance using the resource-based view (RBV) theory. It also looked into the role of transactional leadership in regulating these correlations to draw up the policies for the post-pandemic era. A quantitative study is conducted and a questionnaire was distributed randomly among the Ministry of Health of the Sultanate of Oman and 233 people have participated in the questionnaire survey. PLS-SEM was utilized to analyze the data. In this study, performance appraisal, job enlargement training, and work enrichment all have a considerable influence on employees' adaptive performance. Furthermore, transactional leadership moderates the linkage between job enrichment and employee adaptive performance. As a result, the higher the organization's attention on certain HR policies, the better their adaptive performance. HR practices are important predictors of adaptive performance; thus, managers and practitioners should take into account workers' adaptability to encourage more adaptive behavior in the workplace. This article further discusses the study's weaknesses as well as future research directives on HRM practices and adaptive performance.

KEYWORDS

job enlargement, performance appraisal, transactional leadership, sustainable human resources, post covid

1 Introduction

Employees' ability to manage crises, react swiftly, and confront new difficulties becomes increasingly vital as the environment grows more chaotic (Charbonnier-Voirin & Roussel, 2012; Chua et al., 2021). Prior views on job performance have failed to account for the full range of human actions that add to job success in unpredictably complex systems. Adaptive performance has garnered a lot of attention as a technique to better understand the dynamic nature of employee performance in today's fast-paced business environment (Park, & Park, 2019; Huntsman et al., 2021). The importance of openly addressing workers' flexibility to changes in the workplace is demonstrated through adaptive performance. Adaptive performance can lead to good consequences such as improved performance capacity and professional achievement on a personal level (Shoss et al., 2020; Mc Loughlin, & Priyadarshini, 2021). Organizational outcomes such as change in management, organizational learning, and meeting changing customer expectations can all be aided by employee adaptability (Dorsey et al., 2010). It can help businesses innovate, maximize their current skills, and adapt to changing surroundings (Ahmad et al., 2019; Shoss et al., 2020).

Even though the number of existing pieces of literature from many sectors has expanded over the last decade, there is a need to synthesize previous research from various angles. The jargon employed to discuss workers' adaptive performance, for example, may be perplexing to readers (e.g., agility, flexibility, adaptability, and adaptive conduct). Furthermore, several studies in a variety of nations have looked into the link between HRM practices and subjective and financial metrics of organizational success (Moideenkutty et al., 2011). The association between HRM practices and employee adaptive performance, as well as the moderating role of transactional leadership, has not been studied in countries of the Middle East such as the Sultanate of Oman, to our knowledge.

Transactional leadership as a moderator has been introduced in this study to look at the association between HRM practices and employee adaptive performance in the Sultanate of Oman. Since HRD has identified performance as a critical issue, employee adaptable performance should be a top concern (Al Asbahi et al., 2019; Kang et al., 2021). Organizations must analyze and improve people's adaptable performance concerning their usual work performance since the capacity to adapt has become increasingly important. HRD scholars must include adaptive performance as an extension of conventional performance since it reflects the current changing business environment. Only a few studies, on the other hand, have looked at ways to improve workers' flexibility (Islam et al., 2018; Huntsman et al., 2021).

As a result, the authors of this research work feel that HRD may help with the identification of reasons as well as the creation of a plan and approaches for boosting employee adaptability. HRD's emphasis on building capabilities and increasing performance may aid organizations in identifying methods to increase workers' adaptive performance by offering learning and development opportunities and altering corporate culture and practices. More studies on HRD research is required to better understand workers' adaptable performance and to aid businesses in improving their employees' adaptive performance to survive and prosper (Park, & Park, 2019; Dai et al., 2021). However, despite the importance of adaptive performance in performance enhancement, as demonstrated by the "Strategic HR" literature, which consistently found connections between packages of HR practices and various indices of firm performance, the function of organizational HRM practices as predictor variables of adaptive performance remains underexplored (Tabiu et al., 2020). Therefore, this study looks at the impacts of performance evaluation, training, work enrichment, job expansion, and employee involvement on workers' adaptive performance, as well as the impact of transactional leadership on these crucial linkages.

The main goal of this research is to add to the body of knowledge on adaptive performance by looking at the impact of HRM practices (performance evaluation, training, work enrichment, job enlargement, and employee engagement) on adaptive performance prediction. This study aims to contribute to understanding the reasons for under-researched adaptive performance, particularly in developing countries, according to the comments of Krijgsheld et al. (2022) on the absence of HRM studies from developing countries like Oman.

2 The resource-based view theory

According to an earlier study, RBV is a solid rationale for implementing strong HR practices (Newman & Sheikh, 2014). According to the RBV, "human resource systems can contribute to sustained competitive advantage through facilitating the development of competencies that are firm-specific, produce complex social relationships, are embedded in a firm's history and culture, and generate tacit organizational knowledge," as stated previously (Kuvaas, 2007; Qi and Wang, 2106).

The RBV method seems to give a solid theoretical platform for examining differences in organizational performance, particularly in terms of human resources. This is because HR practices may contribute to the development of skills and knowledge that boost competitiveness and performance (Mu et al., 2018). The idea has become a popular one when it comes to strategic HRM and how human resources and associated HR

practices may affect corporate performance. In addition to human capital, the RBV considers intellectual capital, human resource strategy, and organizational performance. RBV has made a substantial contribution to the area of human resource management, which is expanding (Barpanda and Bontis, 2021) and has been eagerly adopted by both practitioners and scholars in the HRM profession (Alemzero et al., 2021).

3 Literature Review

3.1 Performance appraisal

Employees are a critical investment for firms because they have the power to affect organizational success (Ogiemwonyi et al., 2020). In the competitive environment, employees may affect the growth of the organization. As the ones responsible for employee performance for organizational success and competitive edge, firms are increasingly going to invest in various development activities such as coaching, development centers, and career planning to improve performance (Al-Hussaini et al., 2019). Performance evaluations have been shown to have a major impact on an employee's ability to enhance their performance and effectiveness. Performance appraisal is the process of reviewing an employee's performance over some time (DeNisi and Smith, 2014).

It refers to "activities through which organizations seek to assess employees and develop their competence, enhance performance and distribute rewards. It sometimes becomes a part of a wider approach to integrating HRM strategies known as performance management" (Al-Busaidi et al., 2021). Although the performance appraisal system is recognized as the most significant of all human resource activities (Shrivastava and Purang, 2011), limited studies have been conducted on the improvement of employees' performance (DeNisi and Pritchard, 2006).

This might be one of the reasons why most companies focus on the overall effectiveness and efficiency of their performance appraisal rather than the influence on employee performance (Longenecker & Fink, 2017). Establishing an effective performance appraisal is one of the most challenging tasks for HR professionals in terms of performance growth (Harrington and Lee, 2015). As a consequence, research into how performance evaluation systems may be made more acceptable to employees and how they affect employee performance is urgently needed (Sharma & Sharma, 2017; Sabiu et al., 2018).

3.2 Performance appraisal and adaptive performance

Firms invest in their staff to improve human capital and gain a competitive edge. They similarly examine their human capital in an attempt to determine staff development needs and changes to achieve better performance. To get the greatest outcomes, organizations provide feedback to employees and anticipate future development needs, using performance evaluation or employee evaluation tools. To be recognized and rewarded, employees must have their work assessed (Levy et al., 2015). Employees who are satisfied with their performance reports are more inclined to participate in training programs, which may help them improve their overall performance. Furthermore, a strong and appropriate performance review has the potential to improve both employee performance and healthcare quality (Majidi et al., 2021). According to Kuvaas (2007) and Van Woerkom and Kroon (2020), one of the main goals of performance appraisal is to motivate individuals to improve their performance. As a consequence, we expect a performance evaluation that aids employees in discovering, developing, and employing the attributes that allow them to perform at their best to have a positive influence on their adaptive performance. As a result, we came up with the following hypothesis:

H1. Performance appraisal positively affects adaptive performance.

3.3 Training

People must be taught to adapt to workplace changes as a result of dynamic changes in the work process and the global competitive environment (Tumi et al., 2021). Organizations must provide proper and advanced training to exchange key skills and knowledge. Training is the most appropriate form of motivation for a company to increase its employees' abilities. Training affects people's general self-efficacy, which leads to increased motivation and confidence (Tai, 2006). Training is a process in which people gain a particular level of competence to help the company accomplish and its goals (Abbas and Ali, 2021). Al-Ali et al. (2016) stated that "training prepares people to do reviews their present jobs and development prepare employees needed knowledge, skills, and attitude;" authors also argued that training prepares people to do reviews of their current occupations. To put it in context, training is a key tool for a company to fulfil its employees' rising need for current knowledge and abilities. HR managers assist employees in carrying out their obligations without stress by instilling confidence in their abilities *via* effective training (Mangkunegara and Waris, 2015 Lee and Wei, 2015).

There is substantial link between training and employee motivation to perform (Hughes et al., 2018; Jaworski et al., 2018). Al-Hussaini et al. (2019) defined training as a set of activities intended to enhance employees' knowledge, talents, and competencies, resulting in increased motivation and, as a result, big positive outcomes. Effective training programs are considered a tool to improve employees' attitudes and behaviors. Structured training has a considerable impact on nurse performance, according to research done at a Jordanian military hospital (Al-Ali et al., 2016; Ogiemwonyi et al., 2020).

Teaching nurses the required skills and knowledge to deal with patients, they claim, will increase hospital productivity.

3.4 Training and adaptive performance

Employee training is a popular HR strategy since it enhances employees' abilities and experiences, enabling them to engage in more positive behaviors (Nasurdin et al., 2015; Hassan et al., 2022). Staff training is critical since it determines whether a company succeeds or fails.

According to Han and Williams (2008), training may help employees to adapt to an unanticipated situation by providing them with not just the essential skills and knowledge that extend beyond their current jobs but also by supporting them in adapting to such conditions. Similarly, Chen et al. (2005) discovered that employee adaptability training programs help workers to develop the essential skills, experience, and knowledge to perform adaptively in the workplace. If a person is exposed to settings that need organizational modifications, for example, he or she will be able to function effectively in a future scenario that requires similar adaptation (Şahin and Gürbüz, 2014). Experience with similar events may be beneficial in improving adaptive performance (Pulakos et al., 2006). Thus, we hypothesize that

H2. Training positively affects adaptive performance.

3.5 Job enrichment

Job enrichment is described as a wider range of job content in the workplace that is achieved *via* employee autonomy. If employees are included in the decision-making process, they will feel more accountable for their work-related behavior and outcomes. Employees' ability to juggle many tasks contributes to a more enjoyable work environment and motivates them to enhance their performance (Garg and Rastogi, 2006). Dai et al. (2021) defined job enrichment as the incorporation of elements into job performance that favors many different tasks to be done, the autonomy about the work that needs to be done, greater involvement in decision-making, increased responsibility, performance feedback, and participation in change initiatives. Employees who have received job enrichment may arrange their schedules and be in charge of their responsibilities while at work. Employee autonomy may reduce work-related family conflicts while simultaneously boosting job satisfaction. According to research, employees who have the option to choose their working hours and processes are more motivated (Baral and Bhargava, 2010; Bayo-Moriones et al., 2019).

The value of autonomy may be seen in group performance as well. Team members that have the flexibility to choose team members with the requisite skills and expertise may be more creative and productive in attaining the organization's goals (Yang and Choi, 2009). According to various studies, improving employees' work experience improves their motivation and job devotion. In addition, work enrichment significantly enhances self-control, self-actualization, and self-respect (D'Souza et al., 2022).

3.6 Job enrichment and adaptive performance

As stated in a study by Azeez and Abimbola (2016), job enrichment was shown to be a significant predictor of employee happiness, motivation, and performance at public colleges in Nigeria. In the study, job enrichment was found to provide a variety of benefits to employees, including the development of new skills, a sense of purpose in one's work, and the recognition and appreciation of co-workers and superiors. It was also found to increase employees' sense of personal responsibility, sense of accomplishment, and involvement in decision-making. To their surprise, individuals want workplace autonomy since it allows them to make their judgments about how to fulfil their duties. According to some studies, work enrichment is necessary to encourage employees to carry out their responsibilities and achieve high levels of job performance (Van Yperen et al., 2016).

In addition, job enrichment gives workers more control over how they work and how much time they spend on it. Reducing stress at work and inspiring employees to perform well may be aided by this (Tumi et al., 2021). Employees need to be exposed to different types of duties to increase their motivation. Workers might feel more like people rather than machines when their jobs are well structured and well managed (Wood, 2018, p. 51). Employees who believe that the firm owns them put forth their best effort when they are provided chances for job enrichment. The job enrichment approach has a significant impact on employee performance (Saleem et al., 2012). Thus, this projected hypothesis is as follows:

H3. Job enrichment positively affects adaptive performance.

3.7 Job enlargement

The broadening of career options for organizational employees was a major focus of the job enlargement component. In today's workplace, employees want a job that offers a wide variety of tasks and responsibilities to help them grow professionally and succeed in their careers. As a consequence, increasing the number of jobs is considered helpful in terms of inspiring employees to work harder toward the organization's objectives (Tumi et al., 2021). Enlarging the scope of a person's employment entails adding new tasks and responsibilities. The main assumption of work expansion is that increasing the diversity of duties done will alleviate fatigue and boredom, as well as stimulate individuals to perform at higher levels (Hadidi and Abzakh, 2021).

When employees are empowered, they need to be given greater authority and duties, which means that more work

needs to be done on the shop floor (Farah et al., 2018). Saleem and colleagues (2012) described employees in ringed jobs being given more responsibility throughout their workdays as job expansion. However, this does not indicate that employees will be able to expand their responsibilities beyond what they are capable of now. By learning new tasks, employees will be able to improve their talents and obligations, which will allow them to take on more responsibilities and duties in the future.

3.8 Job enlargement and adaptive performance

It's been shown in several studies that expanding the scope of workers' work allowed them to better use their skills and abilities in more challenging roles. It gives employees the freedom to plan their workdays and their schedules according to their preferences. Reducing stress at work and inspiring employees to perform well may be aided by this (Tumi et al., 2021). Employees need to be exposed to different types of duties to increase their motivation. Employees that have a sense of ownership in the firm are far more inclined to double their best efforts to achieve organizational goals as a consequence of job creation. Thus, the researchers hypothesized that

H4. Job enlargement positively affects employee adaptive performance

3.9 Employee involvement

The leaders of an organization should make a concerted effort to promote employee engagement by offering visible chances for individuals or groups at all levels of the company to have a greater voice (Prieto et al., 2020). When new ideas are generated, disseminated, and implemented in the workplace by employees, they represent an important source of innovation (Busch-Casler et al., 2020). The engagement of the whole firm's employees in improving the working environment, product quality, equipment productivity, and, finally, the competitiveness of the organization is how employee involvement is described by the industry. Several early studies stressed employee engagement because of its vital role in delivering services and formulating consumer experiences. The relevance of workers, however, has also been highlighted in recent research, stressing the value of employees' awareness of users, along with their knowledge of organizational (work) practices (Mu et al., 2018).

3.10 Employee involvement and adaptive performance

Increased productivity may be attributed to increased employee involvement in both the private and public sectors. Participation by employees is directly related to performance, which is closely tied to the human capital theory, as stated by the cognitive model. Front-line workers are seen as more knowledgeable about their occupations than managers. By including people in management, these data may be utilized to make better decisions and improve product quality and efficiency. Getting employees involved in the management and having frequent conversations with their co-workers may improve their problem-solving skills and job expertise. Human capital assets, such as knowledge and skills, may provide organizations with a competitive advantage that is difficult to replicate. According to certain empirical studies and meta-analyses, engagement has positive and direct benefits on productivity (Guthrie et al., 2009).

Only a few studies have looked at other dimensions of employee participation that support this important relationship, despite significant advances in this area. It has also not been adequately investigated in the healthcare industry, despite its importance for healthcare organizations. A goal of employee engagement is to increase members' participation in decisions that have an impact on their productivity and well-being (Glew et al., 1995). Therefore, the study hypothesized that

H5. Employee involvement positively affects adaptive performance.

3.11 Transactional leadership as moderator

When compared to transformational leaders, transactional leaders are exclusively concerned with the transactional nature of their connections with their followers, unlike transformational leaders. Contractual agreements and reciprocal advantages form the basis of the relationship between the leader and subordinates (Pichlak, 2021). Expectancy theory (Vroom, 1964) and equity theory are claimed to be the roots of the transactional leadership style. Both theories highlight the importance of task completion and performance-related incentives (Burke et al., 2006). Individuals are more likely to achieve their goals if they believe they will be rewarded fairly and appropriately for their efforts, according to these views. There is evidence to suggest that leaders who follow the principles of transactional leadership may enhance the performance of their teams by setting clear objectives, offering specific instructions, and monitoring progress toward those goals. Using a reward contingency approach, transactional leaders can encourage their teams to meet project objectives since they are skilled at giving performance-based incentives and placing an emphasis on their employees' extrinsic demands and timely job completions. The leaders are also obliged to fix any flaws or errors that they find (either actively or passively) to guarantee that the projects are completed successfully. As a result, transactional

leadership is more likely to lead to desired objectives (Abbas & Ali, 2021). As a result, transactional leaders 1) are reactive rather than proactive, 2) operate within the organization's culture, 3) ensure that people accomplish their objectives *via* a rewards-and-punishment system, and 4) demonstrate the style of management by exception (D'Souza et al., 2022).

With the economic change, transactional leadership has become a prominent leadership style in several organizations (Hossain et al., 2022). To keep control, transactional leaders focus on the process rather than the content and offer their followers concrete rewards for accomplishing a specific objective (Tahir et al., 2014). In transactional leadership, the leader and his or her subordinates agree on what incentives or acknowledgment the subordinate would get for achieving a certain level of performance. When the agreed-upon level of performance is met, awards, acknowledgment, or both are given. Under such leadership, workers would have high expectations of organizational benefits after they have paid their efforts out, increasing the concept of reciprocity (Shoss et al., 2020). The stream of research suggests a positive relationship between transactional leadership and employee outcomes. Furthermore, several studies have shown that transactional leadership has a strong influence on various relationships (Awan et al., 2021). For instance, previous studies have shown that transactional leaders can elevate the effect of front-line employees' behaviors on their performance because they lead by providing concrete directions, specifying clear expectations, and providing instructions on how to complete tasks to achieve desired outcomes (Prasad and Junni, 2016). However, human resource practices and adaptive performance has limited data to show the relationship that could be strengthened in an organization with a transactional leadership style. Figure 1 shows the conceptual model and hence the study posited the following:

H6. Transactional leadership positively moderates the relationship between performance appraisal and employees' adaptive performance.

H7. Transactional leadership positively moderates the relationship between training and employee adaptive performance.

H8. Transactional leadership positively moderates the relationship between job enlargement and employee adaptive performance.

H9. Transactional leadership positively moderates the relationship between job enrichment and employee adaptive performance.

H10. Transactional leadership positively moderates the relationship between employee involvement and employee adaptive performance.

4 Methodology

4.1 Data, measurement, and methods

A quantitative survey study was conducted among the employees of the Ministry of Health in the Sultanate of Oman, and a questionnaire was emailed to them. The questionnaire survey was conducted during the COVID-19 era; about 500 emails were sent to the different employees associated with the Ministry of Health, and over a period of 3 months, a total of 233 responses were received. Respondents were informed that the research was only for academic reasons and that all surveys were anonymous and could not be linked to any specific individual to protect their privacy and avoid social desirability bias. Questionnaire items were adopted from past studies. Eight training items were taken from the study by Tahir et al. (2014); seven items of job expansion were adopted from the study by Mwihaki (2017); job enrichment from the sample provided by (Keir and Youssif, 2016). Seven items of adaptive performance measures (Pradhan & Jena, 2017). Additionally, a 5-point Likert scale from 1—strongly disagree to 5—strongly agree was used for all the items.

4.2 Preliminary analysis

Before assessing the model, we tested the data for multivariate normality. The skewness coefficient (= 23.535) and kurtosis coefficient (= 98.65766) were both above the threshold values of 2 and 20, suggesting non-normally distributed data, according to Mardia's coefficient approach (Kline, 2011; Byrne, 2013). Therefore, PLS-SEM, which uses a non-parametric inference technique (bootstrapping), is better suited for this task (Sarstedt et al., 2017). Expectation maximization was used to deal with missing values. Using Mahalanobis distance, no outliers were found.

There were 57.1% female respondents and 42.9% male respondents, with the majority of the respondents being under 30 years of age, which is 45%, followed by 30–35 years of age, which is 31.8%, then 36–40 years, which is 11.6%, and the least representation is from 41 to 45 years, which represents only 11.2%. In terms of marital status, 31.8 percent of the people were married and 68.2% were single. Those with five to 10 years of job experience contributed 47.6% of the total, followed by those with fewer than 5 years (35.6%) and those with eleven to 15 years of work experience (16.7%). People having a diploma were more likely to take part in this research than those without one (47.6%), followed by those with a Bachelor's degree (28.3%), then secondary (12.0%), then a Masters degree (10.7%), and those with other backgrounds (1.3%).

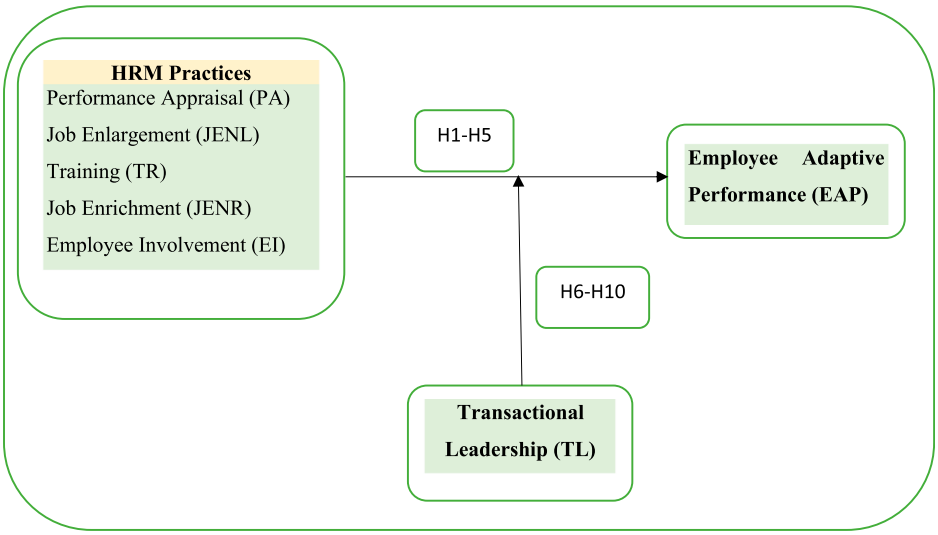

FIGURE 1
Conceptual model.

4.3 Common method variance

The common method variance (CMV) is recognized for exaggerating the strength of the correlations between the variables in the model since all of the responses come from the same source. You may utilize one of Harman's single factors to identify bias result if any largest variable explained by an individual component was 33.60 percent (Podsakoff et al., 2003). The data demonstrate that CMV is not a danger in the present study.

4.4 Statistical techniques

The research model was analyzed using Smart-PLS 3.3 of the Partial Least Square-Structural Equation Modelling (PLS-SEM) technique. Analytical tools such as PLS-SEM may be used to reduce type II errors and can accommodate formative dimensions as well as a complicated model. Non-parametricity of PLS-SEM allows researchers to relax the requirement for normally distributed data (Hair et al., 2019) and Sarstedt et al. (2017). The technique can also be used to analyze data in studies with small sample sizes and exploratory research. Analysis of multi-item structures with direct and indirect channels is made easier with this tool. Therefore, the measurement and structural model were assessed using the PLS-SEM technique.

4.5 Measurement model

In the measurement models, internal consistency reliability, convergent validity, and discriminant validity were investigated. Cronbach's Alpha and composite reliability were used to assess the constructs' reliability and rho-A. Table 2 reported the thresholds of Cronbach's Alpha, composite reliability, and rho-A exceeded the 0.70 benchmark (Hair et al., 2017), suggesting adequate consistency among the measures.

Convergent validity was assessed using indicator loadings, composite reliability (CR), and average variance extracted (AVE). In this study, as shown in Figure 2 and Table 1, the convergent validity was achieved as the indicator loadings go beyond the threshold of 0.70, the composite reliability exceeds 0.70, and the AVE is above 0.50 (Hair et al., 2017). To achieve the required convergent validity, two items (AP1 and EI1) were deleted as they fall short of the threshold.

The heterotrait-to-monotrait (HTMT) ratio was used to assess discriminant validity using the thresholds of 0.85 and the Fornell & Larcker criterion (Henseler et al., 2015). Table 2 demonstrates that the correlation among all the factors was below the value of 0.90 (HTMT), and it also shows that diagonal values (bold) are larger than the off-diagonal. These confirmed the evidence of satisfactory discriminant validity. Furthermore, Table 4 shows that all variables reported variance inflation factors (VIFs) less than the benchmark value (Becker et al., 2015; Hair et al., 2017), concluding that there was no multicollinearity concern among the predictor constructs.

4.6 Structural model: Hypotheses testing results

The structural model in this study was assessed using five steps as recommended. First, the variance inflation factor (VIF) was

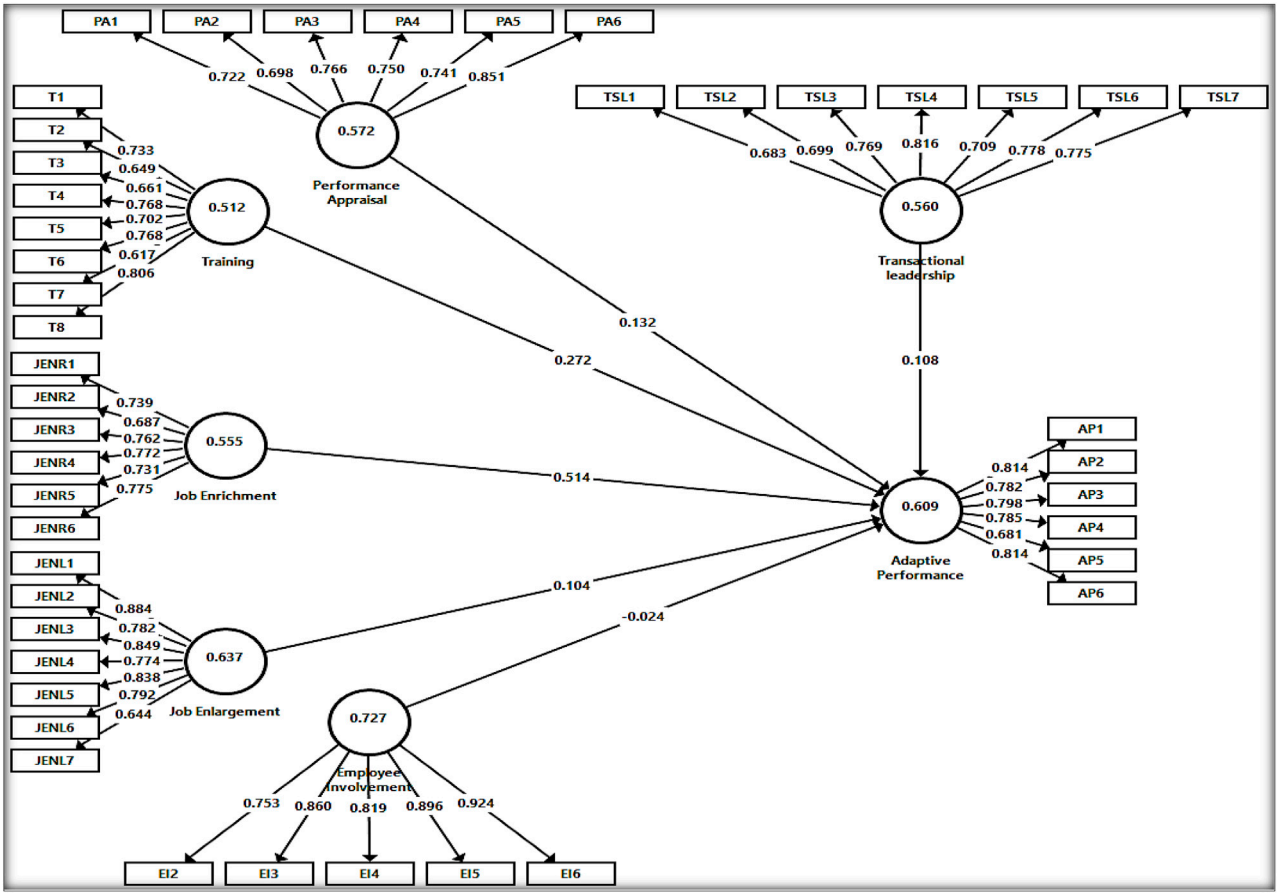

FIGURE 2
Measurement model with factor loadings and AVE values from PLS algorithm.

scrutinized to verify the lateral collinearity issue. Table 3 shows that inner VIF values were less than the cut-off score of 5 (Becker et al., 2015; Hair et al., 2017), indicating that the problem of the multicollinearity issue is not a concern. Second, the importance of parameter estimates in the structural model was assessed using t-values, *p*-values, and the confidence intervals (95% bias-corrected and accelerated). The hypotheses in the structural model were tested in this study using a bootstrap re-sample technique with 5000 sub-sample iterations. The results of the relationships are presented in Table 3 and Figure 3; performance appraisal, job enlargement, job enrichment, and training have a significant relationship with adaptive performance (H1: $\beta = 0.156$, $p = 0.045$), (H2: $\beta = 0.105$, $p = 0.047$), (H3: $\beta = 0.510$, $p = 0.000$), and (H4: $\beta = 0.302$, $p = 0.000$), respectively, and therefore, they were all supported. Furthermore, the relationship between employee involvement and adaptive performance was not significant (H4: $\beta = -0.015$, $p = 0.200$) and, hence, not supported.

The third step included investigating in-sample predictive power (the coefficient of determination, R2). The results revealed that 56.4% of the variance in adaptive performance was explained by exogenous variables (performance appraisal, job enlargement, job enrichment, training, employee involvement, and transactional leadership) (refer to Table 3).

Fourth, the construct's effect size was calculated using Cohen's f^2 (Cohen, 1988). Similarly, effect size (f^2) values greater than 0.02, 0.15, and 0.35 represent a small, medium, and large effect, respectively (Cohen 1988). Looking at the f^2 values in Table 3, we can see that all the exogenous variables demonstrated small to medium effect size in generating R^2 for the endogenous variables.

Fifth, the structural model's prediction accuracy may be evaluated by computing Q^2 values using a blindfolding technique (Stone, 1974; Geisser, 1975). The endogenous variables (i.e., adaptive performance = 0.328) showed the predictive accurateness of the model ($Q^2 > 0$), as shown in Table 3.

The model's predictive accuracy was further investigated by concentrating on "a unique technique for measuring a model's out-of-sample prediction" (PLS predict) (Hair et al., 2019; Shmueli et al. .2019). According to the results of the PLS

TABLE 1 Constructs' validity and reliability.

Constructs	Items	Loadings	CA	CR	AVE
Adaptive performance	AP1	0.814	0.871	0.903	0.609
	AP2	0.782			
	AP3	0.798			
	AP4	0.785			
	AP5	0.681			
	AP6	0.814			
Employee involvement	EI2	0.753	0.904	0.930	0.727
	EI3	0.860			
	EI4	0.819			
	EI5	0.896			
	EI6	0.924			
Job enlargement	JENL1	0.884	0.904	0.924	0.637
	JENL2	0.782			
	JENL3	0.849			
	JENL4	0.774			
	JENL5	0.838			
	JENL6	0.792			
	JENL7	0.644			
Job enrichment	JENR1	0.739	0.847	0.882	0.555
	JENR2	0.687			
	JENR3	0.762			
	JENR4	0.772			
	JENR5	0.731			
	JENR6	0.775			
Performance appraisal	PA1	0.722	0.850	0.889	0.572
	PA2	0.698			
	PA3	0.766			
	PA4	0.750			
	PA5	0.741			
	PA6	0.851			
Training	T1	0.733	0.875	0.893	0.512
	T2	0.649			
	T3	0.661			
	T4	0.768			
	T5	0.702			
	T6	0.768			
	T7	0.617			
	T8	0.806			
Transactional leadership	TSL1	0.683	0.869	0.899	0.560
	TSL2	0.699			
	TSL3	0.769			
	TSL4	0.816			
	TSL5	0.709			
	TSL6	0.778			
	TSL7	0.775			

Note: F.L = factor loadings; CA = Cronbach's Alpha, CR = construct reliability; AVE = average variance extracted.

predicted evaluation in Table 4, part of the Q^2 value provided by the PLS-SEM estimate is greater than the LM model, indicating that the model's predictive capacity is supported. Following the recommendations outlined by Shmueli et al. (2019), the predictive findings show that several endogenous variables in the PLS model produced a low predictive error when compared to the LM model, suggesting that the model has medium predictive potential. Finally, the researchers used the standardized root mean square residual to evaluate the model fit (SRMR). The composite factor model fits the data in this article since the SRMR is 0.077, which is less than 0.08.

4.7 Moderating analysis

To test H6-H10, the moderation analysis was conducted by taking the interaction effect of transactional leadership into account (see Table 3 and Figure 4). The bootstrap results presented that only one hypothesis was supported, that is, transactional leadership moderates the path between job enrichment and adaptive performance (H8: $\beta = 0.183$, $p = 0.027$), but did not moderate the relationship between the other exogenous variables (performance appraisal, job enlargement, employees' involvement, training, and adaptive performance). Hence, H6, H7, H9, and H10 were not supported. Furthermore, interaction has been graphed to enable important interpretation; hence, Figure 4 shows the plots of the two-way interactions. It illustrates that the linkage between employee involvement and adaptive performance was moderated by transactional leadership.

5 Discussion

Adaptable performance research was investigated in this study and examined the principal aspects of adaptive performance on an individual level. The study also explored the interaction effect of transactional leadership on the connection between HR practices and adaptive performance. The study has introduced transactional leadership as a mediator for better understanding of how HR practices and adaptive performance are linked. According to studies and HR practices, successful HR practices may influence individual behavior (DeNisi and Smith, 2014). Adaptive performance was shown to be positively linked to performance evaluation, job expansion, work enrichment, and training in the present study. This study corroborated the previous findings; even though the association between job enrichment and adaptive performance was shown to be significant, transactional leadership enhanced the performance of the employees.

However, transactional leadership, on the other hand, does not affect the link between job enlargement, employee involvement, training, performance appraisal, and adaptive performance.

This research found that companies should invest in their employees to strengthen their human resources and acquire a competitive edge. Human resources are also evaluated, to identify training needs and ways to boost employee performance (Lira, 2015). To get the greatest performance out of their staff, companies utilize 1) tools for performance evaluation and personnel assessment. For employees to be recognized and rewarded, their work must be evaluated (Levy et al., 2015). Performance evaluations that make employees happy are more likely to get them involved in learning activities, which may help them enhance their skills (Nikpeyma et al., 2013). 2) Employee training as a way of enhancing their abilities, competence, and

TABLE 2 Discriminant validity: Fornell & Larcker.

	Constructs	1	2	3	4	5	6	7
1	Adaptive performance	0.781						
2	Employee involvement	0.466	0.852					
3	Job enlargement	0.489	0.441	0.798				
4	Job enrichment	0.698	0.624	0.562	0.745			
5	Performance appraisal	0.495	0.477	0.404	0.536	0.756		
6	Training	0.553	0.41	0.392	0.494	0.433	0.716	
7	Leadership	0.473	0.482	0.501	0.604	0.568	0.567	0.748
				HTMT				
	Constructs	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	Adaptive performance							
2	Employee involvement	0.523						
3	Job enlargement	0.545	0.482					
4	Job enrichment	0.730	0.718	0.636				
5	Performance appraisal	0.566	0.530	0.458	0.619			
6	Training	0.508	0.413	0.412	0.493	0.466		
7	Transactional leadership	0.534	0.542	0.572	0.705	0.654	0.634	

TABLE 3 Proposed hypothesis testing results.

Relationships	Std. beta	*t*-values	*p*-values	Confidence intervals		Inner VIF	R^2	F^2	Q^2	Decision
				LLCI	ULCI					
H1: PA-> AP	0.156	2.059	0.045	0.089	0.249	1.678	0.464	0.024	0.328	Supported
H2: JENL -> AP	0.105	1.988	0.047	0.014	0.193	1.580		0.016		Supported
H3: JENR -> AP	0.511	7.088	0.000	0.367	0.619	2.330		0.260		Supported
H4: TR -> AP	0.302	4.558	0.000	0.179	0.421	1.588		0.107		Supported
H5: EI -> AP	−0.015	0.200	0.842	−0.197	0.093	1.759		0.001		Not supported
H6: PA*TL -> AP	−0.045	0.500	0.619	−0.246	0.097					Not supported
H7: JEL*TL -> AP	−0.084	1.166	0.249	−0.286	0.012					Not supported
H8: JER*TL -> AP	0.183	2.285	0.027	0.054	0.280					Supported
H9: TR*TL -> AP	−0.060	0.685	0.496	−0.170	0.095					Not supported
H10: EI*TL -> AP	−0.054	0.920	0.362	−0.173	-0.007					Not supported

Note: AP, adaptive performance; PA, performance appraisal; JENL, job enlargement; JENR, job enrichment; TR, training; EI, employee involvement; TL, transactional leadership.

understanding of their work, resulting in increased flexibility. 3) Employees who have more control over their workdays and their duties have a more fulfilling experience at their jobs. Work-related family problems may be reduced and job performance improved by giving employees more control over their schedules. According to the notion of work enrichment, a job that is "enriched" fosters high levels of three psychological states: knowledge, significance, and obligation. Employees have gained a greater sense of purpose and duty as a consequence of this discovery. 4) The component of job enlargement focuses

TABLE 4 Results of PLS predict.

	PLS			LM			PLS-LM		
	RMSE	MAE	Q^2_predict	RMSE	MAE	Q^2_predict	RMSE	MAE	Q^2_predict
AP1	0.863	0.648	0.367	0.901	0.686	0.308	−0.038	−0.038	0.059
AP2	0.000	0.000	1.000	0.873	0.682	0.397	−0.873	−0.682	0.603
AP3	0.807	0.605	0.420	0.922	0.701	0.243	−0.115	−0.096	0.177
AP4	0.842	0.606	0.351	0.901	0.702	0.256	−0.059	−0.096	0.095
AP5	0.000	0.000	1.000	0.860	0.678	0.320	−0.860	−0.678	0.680
AP6	0.773	0.561	0.426	0.844	0.638	0.316	−0.071	−0.077	0.110

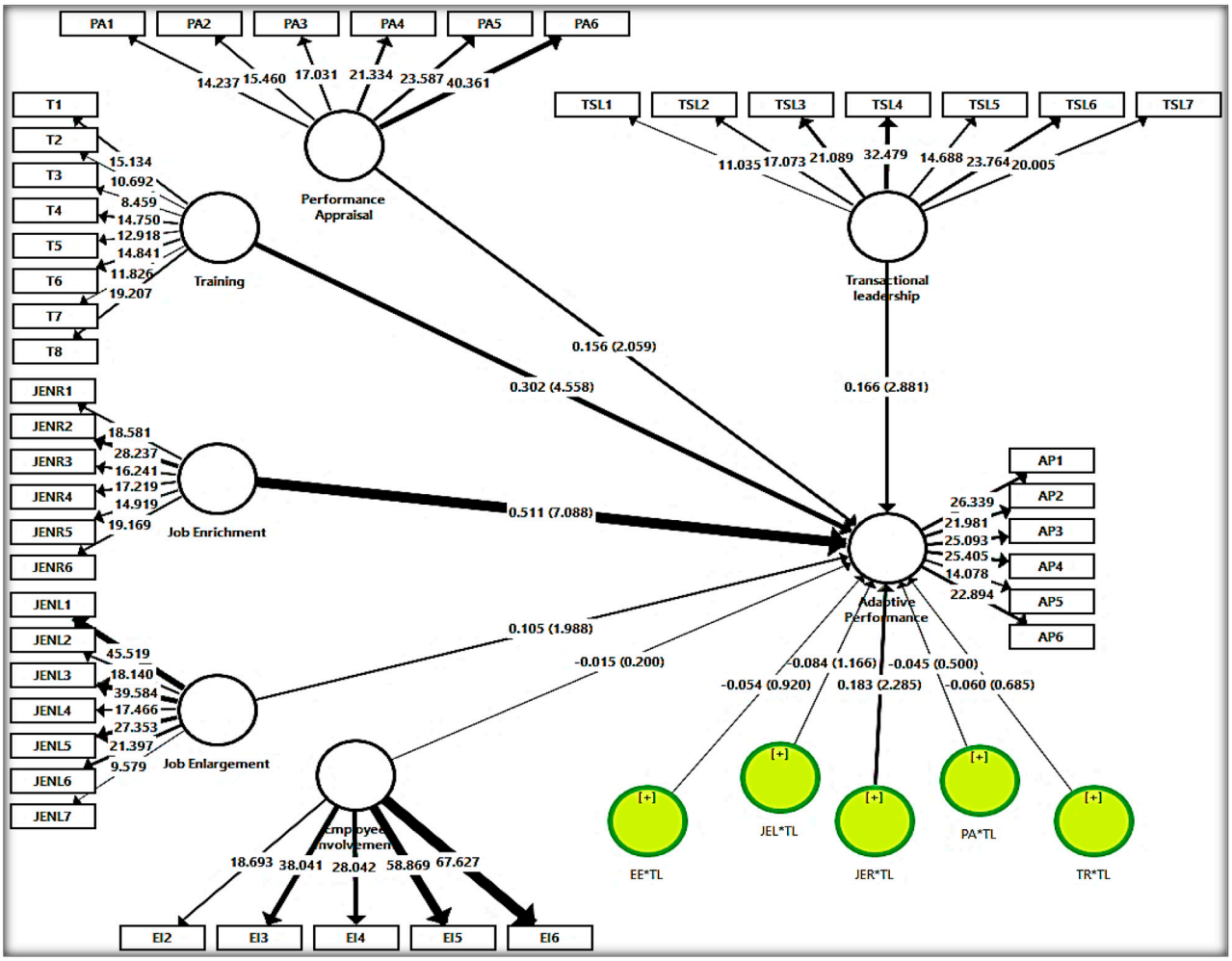

FIGURE 3
Structural model with the path coefficient and *t*-values from the bootstrapping test.

on the scope of professional obligations offered to workers of organizations. In today's workplace, employees want a job that offers a wide variety of tasks and responsibilities to help them grow professionally and succeed in their careers. Employees are more likely to be inspired to work harder and accomplish their goals when their job responsibilities are broadened.

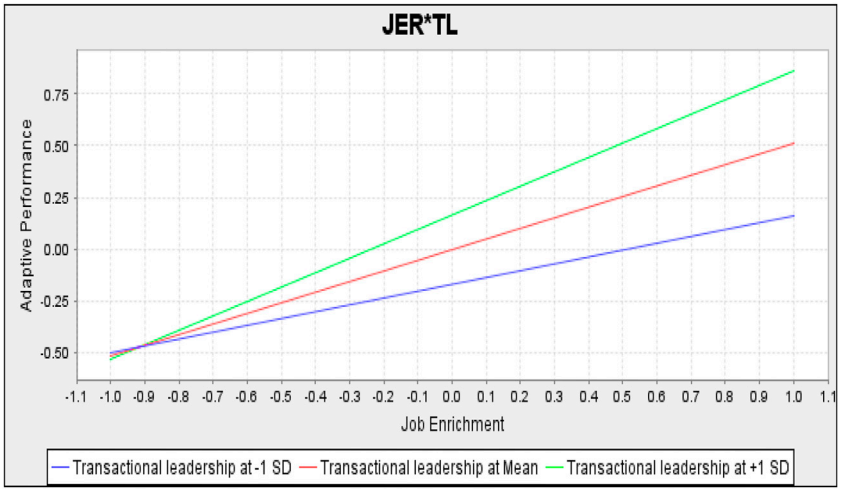

FIGURE 4
Moderation graph.

5.1 Theoretical implications

Worker success in an ever-changing environment may be measured in part by how flexible they are in their job role performance, and that is the topic of this study. An organization's long-term efficiency and success may be greatly predicted by its ability to adapt to a changing environment as well as by its employees' ability to perform well on individual tasks and in context (Dai, et al., 2021). Adaptive performance is influenced by a person's skills and psychological traits of emotional stability, ambition, and the Big Five (Kang et al., 2021). Nonetheless, this study focuses on the elements of employees' jobs and explores the influence of the transactional leadership style on the connection between HR practices and employee adaptive performance.

5.2 Managerial implications

HR practitioners' work is influenced by the formation and resuscitation of individual knowledge and organizational efficiency; hence, adaptive performance is critical to their professionalization (Waight and Greer, 2021). As a consequence, the findings of this research have many important implications for practitioners. In terms of application, our findings imply that firms may reap significant (but distinct) advantages by investing in various aspects of HR processes. HRM practices (job extension, job enrichment, training, and performance assessment) have a considerable and favorable influence on the adaptive performance of employees, according to this research, showing that HRM practices are also major determinants of employees' adaptive performance. In addition, the results contribute to our knowledge of organizational drivers of adaptive performance beyond individual aspects like personality, cognitive ability, and so on, implying that organizations may increase their employees' adaptative performance by employing HRM practices that foster adaptive performance. Health ministry management and other government agencies will benefit from the findings of this study since it shows that HRM practices are important to consider in encouraging more adaptable performance.

6 Conclusion

Researchers have identified a range of methods for boosting contextual and task performance, but employees' adaptability has yet to be investigated. The current research adds to the body of knowledge by presenting human resource practices as a new paradigm for boosting employees' flexible performance. HR practices are a solution for many altering demands, according to the study's findings, including a source of adaptive performance. Furthermore, this study uncovered new evidence about the importance of encouraging transactional leadership in organizations that are going through transformation. Transactional leadership, according to the findings, benefits not just individuals by boosting workplace success but also businesses by improving employee performance.

First, this study expands on the antecedents of adaptive performance by including HR practices in the equation. Adaptive performance, on the other hand, is affected by a wide range of factors, including both individual and organizational traits, as previously stated. To deliver adaptive performance, a combination of personal characteristics and

work environment/group/organizational factors is most probable (Park and Park, 2019). The research that is currently available does not account for all of the possible factors. There has to be a greater focus on how to impact employee adaptive performance by matching the organization's environment to employees' needs and traits, as well as how to influence their adaptive performance. Second, data are collected from a single source, increasing the risk of bias due to a shared methodology; it is recommended to collect the data from more than one source. Last, more studies are required to shed light on the contextual factors that influence adaptive performance. The work environment, for example, may restrict the positive impact of HR policies on performance if employees are not provided with the necessary equipment and goals to perform properly. More study is required to identify potential moderators or mediators of HR practices' impact on adaptive performance.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/ participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

Conceptualization and original data drafting: IA. Methodology design: RS. Methodology validation: SA. Data collection: IA. Data processing and analysis: IA and HA-E. Draft writing: IA. Draft revision and editing: MC.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Energy Efficient Digital Omnichannel Marketing Based on a Multidimensional Approach to Network Interaction

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Digital Omnichannel marketing is viewed the answer to future marketing however, the concept is mired with problems related to the energy and carbon footprinting. Therefore, this study proposed energy efficient network of a complex topology of data access and marketting, where the nodes function as an objects with unique characteristics and create digital customer value network. It is believed that competition has transformed into a contest of online platforms in energy efficency as well in economic efficiency. It is emphasized that there is no alternative to multichannel interaction at the present stage of implementing digital business solutions. In this study, authors have developed omnichannel interaction algorithms based on mathematical models. The proposed approach supplements the digital twin model with economic indicators and methods. Results and analysis of multidimensional structures allows for omnichannel network digital interaction and improves the digital marketing approach. To consider the formation of a network configuration of customer service, developing the idea of digital interaction between participants in consumer value chains. The study conclude and recommend to expand the methodology of digital marketing involving alternative channels of interaction and energy efficency by including a mathematical apparatus for analyzing multidimensional structures (n-D structures).

Keywords: omnichannel interaction, sales network, multi-dimensional structures, green economy, digital development, digital marketing

INTRODUCTION

The principle of any economic activity is based on the an energy efficicy and carbon foorprint reduciton is the challenge of the in the recent decades. However, management considers energy efficiency as the essential factors of interaction in the commercial process and the level of rationality of the company's divisions (Al Asbahi et al., 2019). Sustainable energy is the route to any economic activies in the world (Ahmad et al., 2019). Additionally, the consolidation of business into network structures has been the dominanted trend in the last decade. Moreover, this trend is typical for goods

and manufacturing and service sector enterprises, which occupy an overwhelming market share in developed countries as well in the energy efficency The search for a strategy that maximizes the company's business potential correlates with the desire to expand the reach of the potential client pool. The covid-19 pandemic has become a powerful driver for the development of digital technologies (Bai et al., 2021). The postive and negative aspects of the pandemic especially in the context of the digitlizaiton and bossting omnichannelinig business resulted online business grew rapidly across the world; the online shopping tread among the general public particulary and in business segment has grown many times over (Farah et al., 2018; Donida et al., 2021). When determining the options for enterprise interaction in the Web 4.0 environment, it is necessary, first of all, to rely on the achievements of Internet technologies, primarily mobile, supplied by 4G and 5G networks. The availability of equipment YO and multiple platforms allows for organizing several alternative interaction channels. Digital interaction was facilitated by the device-to-device option and the high speed of data exchange in any format, including geolocation. Additionally, the implementation of IoT technologies has become much more manageable. Hossain et al. (2020) the term omnichannel means an integrated sales experience that melds the advantage of physical stores with the information-rich experience of online shopping.

Omnichannel business interaction has emerged in the digital economy (Cui et al., 2021). The ability to integrate XaaS solutions in cloud service SIM solutions, including mobile interaction, brings corporate CRM (Customer Relationship Management) and ERP (Enterprise Resource Planning) classes to the global level (Rajganesh and Ramkumar, 2016; Alemzero et al., 2021). These integration raises the problem of developing appropriate algorithms for creating the algorithmic basis of digital platforms based on omnichannel interaction based on the digital twin defintion (Barykin et al., 2020). it is possible to expand the scope of the application of optimization methods in making managerial decisions. At the same time, the indices of business process excellence and economic indicators remain the optimization criteria (Golosnoy et al., 2019). Algorithms developed for digital platforms have shown high conversion, promotional activity, and scaling due to the optimal use of these corresponding digital interaction surfaces (Barykin et al., 2021a). There is no alternative to omnichannel interaction at the present stage of introducing digital business solutions. When creating such virtual business platforms, a mathematical basis is needed to complement the technology of single-channel digital twins (Barykin et al., 2020). Podvalny et al. (2017) considered the formation of a network configuration of customer service, developing the idea of digital interaction between participants in the chains of consumer value formation. The mathematical model is proposed to complements the digital twin model with economic indicators (Barykin et al., 2020) using the adopted methods (Barykin S. Y. et al., 2021). Past studies did not address the possibility of taking into account the time spent by the consumer in buying through online or offline channels.

The proposed dynamic programming allows for improving the principles of making managerial decisions for a long planning horizon. By conducting reasoning and derivation of mathematical formalisms for a limited channel dimension to show that the obtained relations are fully scalable and allow any increase in the number of interaction channels available in an actual situation.

LITERATURE REVIEW

The idea of deeveloping digital marketing based on omnichannel network interaction refers to the conceipt Porter's value chain stemming from his book (Porter, 1985) and his earlier ideas about competitiveness (Porter, 1980) as well as his recent publication about creating shared value (Porter and Kramer, 2019). Researchers suppose that future topics could spread over the supply chains transforming to the digital supply networks, incorporating ecosystem partners (Scherbakov and Silkina, 2019). In the modern literature, logistics and supply chain management are considered one of the priority areas of the ongoing digital transformation (Burroughs and Burroughs, 2020). Several authors have considered the digital modifications of logistics, marketing channels, and supply chain management (Mohsin et al., 2015; Matsuda et al., 2019; Cai and Lo, 2020). Researchers couldn't find studies based on the database of the journal of theoretical and applied research on e-commerce by the keywords "Digital omnichannel marketing", "Integration of marketing and logistics", "Dimensions marketing", "Dimension methodology". The work of Lee (2020) considered an omnichannel retail approach and authoer has investigated the influence of omnichannel characteristics on customer satisfaction. Lee (2020) defined omnichannel as a cross-channel retail model that firms use to improve customer experience and maximize firm productivity. Logistics is considered from the position of delivery and return of goods. The perspective of integrating marketing and logistics, the paper notes that an omnichannel approach strategy allows retailers to overcome inefficient organizational barriers that separate retailers from their suppliers and increase transparency for all participants in the supply chain network (Gao and Fan, 2021). Hajdas et al. (2020) considered the consistency of omnichannel concerning customer experience. Attention is paid to customer satisfaction when interacting with the brand through online and offline channels. The study results highlight the importance of consistency between online and offline channels for customers in equal proportions. Consistency denotes the communication between channels. However, the mentioned work considers no integrating marketing and logistics however, example is given for goods related to luxury goods. For clients seeking exclusivity, an omnichannel distribution strategy can be challenging. The most appropriate in this case would be a selective or exclusive distribution strategy. In the analyzed study, attention is also paid to the efficiency of logistics, which refers to the factors associated with the product. The next block of factors related to the market emphasizes the importance of analyzing the needs and attitudes of customers. As an example, a situation is considered in which the company's main target audience does not have sufficient digital skills. It will be challenging to consider the digital channel as an alternative to shopping in such a situation. The next set of

drivers relates to competition factors. New business models based on digital technologies are intensifying competition. As more companies begin to move to an omnichannel approach, more other market participants will follow the same path to remain competitive. The list is completed by a group of factors relating to legality. Tariffs and taxes are seen as an obstacle to implementing an omnichannel strategy. It is also necessary to take into account legal restrictions in the process of implementing an omnichannel approach.

Hossain et al. (2020) studied the barriers firms face in implementing of omnichannel approach. It is noted that both customers and brands show interest in omnichannel. Customers are ready to be active participants in the buying process of omnichannel environment. Brands are equally interested in this approach and admit that they are not as an effective at integrating channels as they would like. Despite the interest, Hajdas et al. (2020); Hossain et al. (2020) and Gao and Fan (2021) omnichannel theory is not well developed in the past stuide. In Hajdas et al. (2020) the omnichannel approach should be considered the next channel integration level. Barriers to applying the omnichannel approach are presented in the form of cases illustrating the factor. Sets of factors are called omnichannel industry drivers. Depending on the industry, they can help or hinder the adoption of omnichannel. One of the blocks is devoted to the factors associated with the product being produced. Product characteristics can either help implement an omnichannel strategy or make it completely unrealistic.

Authors agreed with the point of view of a customer-centric business (Hossain et al., 2020) considering omnichannel marketing as integration between channels to provide a consistent service experience for customers. Several channels are spread over physical stores, websites, direct mail and catalogs, social media sites, review sites, call centers, mobile devices, kiosks, home services, and networked appliances. Saghiri et al. (2017) described the main building blocks and enablers to operationalize the omnichannel system. Verhoef et al. (2015) optimized the customer experience across channels and the performance over channels using numerous available channels and customer touchpoints through synergetic management. Lazaris and Vrechopoulos (2014) supported the view that omnichannel integrates all available channels but not just simultaneous use of channels. The optimization of economically significant indicators of the functioning of the consumer value chain, including those related to the interaction of network participants (Borisoglebskaya et al., 2019) makes it possible to develop a customer-centric business based on multichannel technology. Based on the analyzed sources, we emphasize no approach to forming "seamless" ways of interaction through available communication channels in the presented works. This article proposes to expand the methodology of digital marketing based on multichannel interaction by including the mathematical apparatus for analyzing multidimensional structures.

The main feature of the omnichannel approach is the integration of various channels allowing retailers to glean consumer opinions instantly. The second feature could be a coordinated offering to provide a seamless customer experience. The third feature regards diminishing the distinction between online and offline channels *via* omnichannel marketing (Hossain et al., 2020). In the comprehensive review it is understood past studies has agreeed omminchannel integration quality as a higher-order multidimensional construct however most of the authors have presented in the simmulaiton form and lack of development in the mathemathical expression has found in the work. In this study we aimd to develop the idea of the following four dimensions of Omnichannel Integration Quality described in Hossain et al. (2020) research study. Implementation of the concept of a customer-centric business depends entirely on the level of coordination of enterprises, organizations, and the general consumer pool. Herein, proposed the considering such interaction as a network of complex topology, where the nodes function as objects with unique characteristics. Topology objects characterize participants in the digital customer value creation network. Algorithms preprogrammed in cloud servers of the nodes determine the quality of the implementation of system interaction in omnichannel marketing.

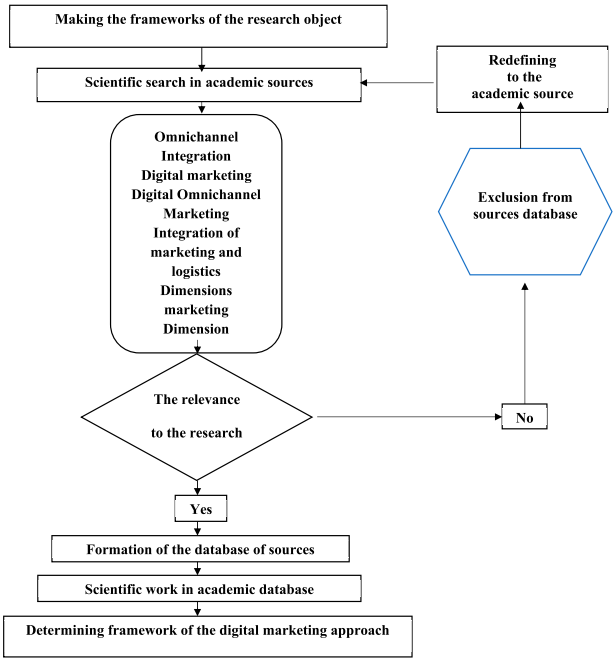

FIGURE 1 | Digital omnichannel marketing framwrok.

MATERIALS AND METHODS

The idea of deeveloping digital marketing based on omnichannel network interaction refers to the concept Porter's value chain stemming from his book (Porter, 1985) and his earlier ideas about competitiveness (Porter, 1980) as well as his recent publication about creating shared value (Porter and Kramer, 2019). In the study, we attempted to develop the idea of the logistics system and marketing instruments which was previosuly studid (Aslam et al.,

2020; Bag et al., 2020; Giordano, 2020). Research frame as shown in **Figure 1** has developed from the literature analysis as the research methodology was applied for the selected keywords and main characteristics were determined which is the part of the secondary data. In this study we aimd to develop the idea of the following four dimensions of Omnichannel Integration Quality described in Hossain et al. (2020) research study.

1. Channel-service configuration (breadth of channel, transparency of channels, and appropriateness of channels)
2. Content consistency (information consistency and transaction data integration)
3. Process consistency (system consistency and image consistency)
4. Assurance quality and sub-dimensions: privacy, security, and service recovery accessibility.

Our approach includes at least one additional dimension (a fifth dimension). Hornik (2021) considered time value functions and customer time spent in online and traditional offline stores, they propose creating and developing an environment to encourage patrons to stay longer doing their shopping. The sixth dimension refers to the value chain's digital interaction based on the marketing and logistics approach (Barykin et al., 2021c). The rapid development of digital platforms in various business segments is a driver for maintaining a high share of online business after the pandemic. Alexander and Kent (2020) stated technology redefines the store space and experience through consumer-facing technologies and tech-enabled services. However, achieving the objectives of a customer-centered business needs some improvement in the logic of interaction with a client. We suppose that the analysis of the n-D structure expands the scope of digital marketing methods.

Basic Formalisms

Analyzing multidimensional (n-D) structures allows for omnichannel network digital interaction and improves the digital marketing approach. Let us introduce the definition of a trade network that combines s many nodes. Each of them has a set of types of interaction with counterparties. Let us define their number as M.

The entire planning horizon is divided into N-many planning periods. This can be either a period when the results of activities are summarized or a period convenient for settlements, as a rule, synchronized with counterparties. Before the planning period, it is necessary to determine the optimal distribution of investments for each type of interaction.

According to statistical data (Barykin et al., 2021c) and business intelligence, the dependencies (Barykin S. Y. et al., 2021) of the planned profit $P_k(z_{kj})$ can be obtained by including similar information on other network players, here denoted as z_{kj} (amount of investment in the network node j for $j = 1, 2, ..., s$ in the direction of k for $k = 1, 2, ..., M$). The problem statement is formulated as follows:

It is necessary to optimize investments in network divisions to determine their volume with the allocation of amounts for types of interaction. The condition is the amount of allowable costs. The expression for the quality functional Ω then takes the form written in **Eq. 1**

$$\Omega = \max\left[\sum_{j=1}^{s}\sum_{k=1}^{M} P_k(z_{kj}\}\right] \tag{1}$$

The development of an appropriate algorithm with the application of the dynamic programming method makes it possible to reduce the problem's solution to a set of recursive formulas. The advantage of this method is mainly the ability to use the results to create software applications embedded in the shell of digital platforms.

ANALYSIS AND RESULTS

Let us consider a network structure with the dimension of s nodes. For most real types of omnichannel interaction, their number M is somewhat limited. We construct a solution for the clarity and convenience of creating formulas for $M = 3$. Thus, it will be immediately apparent that formulas are scalable. It will also become clear that the number M can be set arbitrarily, while the main result will remain the same, only the dimension of the formulas will change. Study of Alexander and Kent (2020), Zhabko et al. (2019), Pilipenko et al. (2019) has shown statistical data in business intelligence software solutions. Using similar techniques, based on the information flow data, dependencies are created to convert investments into profit.

Investing the amount z_{1j} in the network node j (where $j = 1, 2, ..., s$) will result in profit described by the function $F_{1j}(z_{1j})$. Similarly, dependencies can be created between z_{2j} and $F_{2j}(z_{2j})$, and the function $F_{3j}(z_{3j})$ can be used for z_{3j}.

Next, we propose to set a limit amount considering the restrictions on possible costs for each enterprise participating in the network—L_j, where $j = 1, 2, ..., s$. Moreover, in the mathematical model, the entire network consolidated budget shall be placed in the amount of N.

The problem comes down to finding the optimal distribution of investments. Here, investments are calculated between enterprises integrated into the network and for each of the three interaction channels. If, for example, less than three channels are used between nodes, then the corresponding value will be zero.

Mathematically, this is written as finding the maximum functionality ω in the form in **Eq. 2**.

$$\omega = \max\left[\sum_{j=1}^{s}\sum_{k=1}^{3} F_{kj}(z_{kj}\}\right] \tag{2}$$

with restrictions: for the budget of a network subdivision

$$\sum_{k=1}^{3} z_{kj} \le L_j; \tag{3}$$

the total amount of investment across the entire network structure:

$$\sum_{j=1}^{s}\sum_{k=1}^{3} z_{kj} \le N. \tag{4}$$

Additionally, it shall be taken into account that the values of z_{1j}, z_{2j}, and z_{3j} must conform to the inequalities $z_{kj} \ge 0$ for all values of $j = 1, 2, ..., s$ and $k = 1, 2, 3$.

To construct a sequence for solving the problem according to the principle of dynamic programming, we introduce an additional auxiliary function $g_j(w)$. Its value is defined as the maximum profit gained when placing investments w between $j = 1, 2, ..., s$ enterprises of nodes of a commercial network. Further, for a rigorous statement, we consider that inequality 1) reflects a restriction on all arguments of the mathematical model, and restriction 2) has a local meaning and is imposed only on the j th subdivision of the network.

In such a formulation, the recurrence relation based on the Bellman principle is written as follows:

$$g_j(w) = \max\left[\sum_{k=1}^{3} P_k\left(z_{kj}\right) + g_{j-1}\left(w - \sum_{k=1}^{3} z_{kj}\right)\right] \tag{5}$$

where $j = 1, 2, ..., s$ and is denoted by $n = 0, 1, 2, ..., N$, and only nonnegative integer values z_{1j}, z_{2j}, and z_{3j} that satisfy the restrictive inequality $\sum_{k=1}^{3} z_{kj} \le \min(L_j, w)$ participate in the optimization.

The set problem shall also be solved under the conditions of uncertainty of the market environment Due to the scalability of unified distribution solutions, such complex business entities as a commercial network need management support systems much more than usual. In turn, the set problem is classified as a discrete optimization problem, for which methods and algorithms of finding the optimal solution already exist.

Let us represent this problem of choosing the distribution of investments in communication channels in terms of the concept of a discrete controllable system. This allows us to formulate an algorithm and formalize the corresponding recurrent relations. The main advantage of such a solution is the readiness to embed the resulting algorithm for finding the optimal solution in digital platforms. Moreover, the possibility appears to integrate with manufacturing resource planning, enterprise resource planning for optimization of demand-driven techniques/logistics, and widespread customer relationship management solutions that are the core of the Industry 4.0 concept. Next, to solve the multidimensional optimization problem, we transform the obtained expressions of the mathematical model. Let us represent the above equations as finding the maximum sum:

$$F_{1j}\left(z_{1j}\right) + F_{2j}\left(z_{2j}\right) + F_{3j}\left(z_{3j}\right) \tag{6}$$

subject to the following restriction:

$$z_{1j} + z_{2j} + z_{3j} \le y \tag{7}$$

and nonnegativeness of z_{1j}, z_{2j}, and z_{3j} which are natural numbers.

We search for a solution for each of the values of the auxiliary variable y taking the values: $y = 0, 1, ..., L_j$. For these purposes, we then introduce the function

$$f_{1j}(y) = F_{1y}\left(z_{1j}\right),\ y = 0, 1, ..., L_j \tag{8}$$

and apply the recurrent method to the problem (5.6). We transform **Eq. 4** into the form:

$$f_{2j}(y) = \max_{z_{2j}}\left[F_{2j}\left(z_{2j}\right) + f_{1j}\left(y - z_{2j}\right)\right],\ y = 0, 1, ..., L_j \tag{9}$$

where finding the optimal solution is carried out only by the values $w_j \le y$, $z_{2j} \le y$ and the condition:

$$f_{3j}(y) = \max_{z_{3j}}\left[F_{3j}\left(z_{3j}\right) + f_{2j}\left(y - z_{3j}\right)\right],\ y = 0, 1, ..., L_j \tag{10}$$

The result will be the use of the value $f_{1j}(y)$ from **Eqs 7**, **8** for each j in the process of finding $f_{2j}(y)$. Accordingly, for values $f_{3j}(y)$ at $y = 0, 1, ..., L_j$, the search is carried out by the values of the functions $f_{2j}(y)$ and the condition **Eq. 9**. We transform **Eq. 4** and obtain the result from the solution of the relation:

$$\begin{aligned} &g_j(w) = \max\left[f_{3j}(y) + g_{j-1}(w - y)\right],\ j = 1, 2, ..., s, \\ &\text{where } n = 1, ..., N. \end{aligned} \tag{11}$$

The variables are also subject to a condition in the form of a restrictive inequality: $y \le \min(L_j, w)$ at $j = 1, 2, ..., s$.

The proposed algorithm, formulated for a restricted value of $M = 3$, is easily scalable. The process of its calculation can be continued for an arbitrary value of interaction channels. Additionally, from the construction of mathematical formalisms, it can be noted that this model can also be transferred entirely to the cases of nonlinear constraints. This precisely follows the principle of dynamic programming. Practical implementation in software applications also does not cause any difficulties.

To do this, it is necessary to associate the interface of this algorithm with the results of the work of the BI business intelligence module of the corresponding digital platform subsystem in the M2M technology and supplement it with data on cost restrictions. The further calculation is carried out using the available application packages. **Table 1** indicate the results of econimical model of digital ommichannel.

Table 1 indicated the digital ommnichannel forecasted the digitalized marketting efficiency in the emerging economies in this study. It shows that in the emerging countries internet economy is the potential to achieve green growth and an efficient digital ommanichannel maketting. To achieve long-term growth, the digital economy must be completely integrated. Digitalization should be promoted to increase existing economies' production and efficiency. Second, a generational split may reduce the digital economy's eco-efficiency.

Table 2 shows the robustness results that show the reliability of the analysis. The DDF-ML method is used to measure the green, efficient development, which is the standby exogenous variableSecond, Principal component analysis and entropy are utilized to measure the digital economy as the explanatory variable. Third, marginal effects are studied using quantile regression. The table clearly shows that the digital economy still considerably promotes developing high-quality green development while marginal benefits decline. It confirms prior findings and research theories. The results can be used to analyze evolutionary

TABLE 1 | Descriptive statistics.

Variables	Symbol	Interpretation	Obs	Mean	Std. Dev.
Explained variable	Gtfp	High-quality green development	2,259	0.9937	0.2656
Explanatory and threshold variable	Del	Digital ommnichaneel	2,259	1.5433	0.7500
Mediating variables	As	Assurance quality	2,259	0.9835	0.5846
	Gtech	Green technology innovation	2,259	0.9424	0.6237
Control variables	EE	Energy efficity	2,259	10.4660	0.0634
	PC	Process consistencey	2,259	5.5718	0.8765
	CC	Content consistency	2,259	2.4784	2.3492
	Gov	Government intervention	2,259	2.8786	1.8573

TABLE 2 | Robustness check.

Variables	lnGtfp	lnGtfp	lnGtfp	lnGtfp	lnGtfp	lnGtfp
	(1)	(2)	(3)	(4)	(5)	(6)
	Empty cell	Empty cell	Empty cell	$\tau = 0.1$	$\tau = 0.5$	$\tau = 0.9$
Del	0.0793**	0.1211**	0.0948**	0.1177***	0.0788***	0.0465**
	(0.0344)	(0.0500)	(0.0417)	(0.0241)	(0.0112)	(0.0187)
Constant	5.4127	5.9227*	5.5969	2.7370	1.8013	7.4751***
	(3.6601)	(3.5616)	(3.6423)	(2.4913)	(1.1573)	(1.9311)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,529	2,529	2,529	2,529	2,529	2,529
R-squared	0.0307	0.3075	0.3072			
F-statistic	37.93	38.46	38.26			

and differential-difference systems with boundary conditions of the second and third types. For this, it is sufficient to set the second or third boundary condition instead of the Dirichlet boundary condition for the boundary value problem.

DISCUSSION

The implications of the proposed approach for some practical cases. The growing role of digital technologies against the background of the pandemic of a new coronavirus infection actualizes the use of the concept of omnichannel in the activities of airlines. Considering the report Lu et al. (2020) concluded that from the perspective of air carriers, the pandemic caused increased competition. The restrictions caused by COVID-19 have led to a decrease in global demand for air transport. Such a decrease particularly affected small private airlines. Restructuring measures have aimed to reduce costs during the pandemic, which include:

- The cancellation of flights;
- The use of vouchers for future trips instead of refunds for canceled flights;
- Introduction of unpaid leave and freezing of staff salaries;
- No dividend or share repurchase programs; and
- Aircraft grounding.

Even though borders are reopening and several restrictions have ceased to apply, social distancing requirements cause airlines' losses in passenger transportation. We are sure that the increased competition due to the market's oversaturation requires new approaches in interacting with consumers. Omnichannel is a solution to the actual problem of attracting consumers to aviation services. The use of an omnichannel approach improves the interaction with the target audience. We believe that airlines that can apply this approach in their activities to increase the individual focus of their services. A distinctive feature of omnichannel is a "seamless" experience of interaction between the consumer and the enterprise. Digital marketing based on omnichannel technologies allows for interaction through all communication channels, including offline and online. The researchers find different approaches to implementing digital twins in logistics (Booyse et al., 2020; Marmolejo-Saucedo, 2020) and trade networks (Sacks et al., 2020). Study investigated the boundaries of the stability of an evolutionary parabolic system and a differential-difference system with distributed parameters on a selected graph. A computational complexity analysis to demonstrate the computational performance of the proposed solution methodologies could be a topic for future research because of the limitation on the size.

In this study, the development of classical approaches to the study of the sustainability of solutions obtained by using mathematical modeling based on systems of differential equations is carried out. The complex topology of logistics networks within which supply chains are built makes it necessary to apply deeper methods in the study of the

dynamics of logistics flows. Based on the real conditions of logistics activities, it was assumed that this functionality is not always continuous in terms of movement and time parameters. The complexity of solving the problems of forming effective supply chains has increased under the influence of the trend of the consolidation of business into network structures. The application of the results obtained in this work is not limited to the analysis of the sustainability of solutions. Their use is relevant in assessing investment risks, the sustainability of the business.

IMPLICATIONS AND CONCLUSION

Currently, intense competition characterizes the sharply increased segment of the network business. The need to raise an enterprise's competitiveness marks a high demand for software and hardware solutions to support management decisions. In addition, processes within network structures are also becoming more complex due to the growth of types of interaction. One of the decisive drivers of this was the pandemic. The concept of omnichannel business interaction allows the integration of all types of cloud solutions XaaS, SIM solutions, CRM, and ERP. The proposed algorithms allow for choosing the optimal multichannel interaction. The digital twin concept provides the mathematical basis for business optimization and application development in the digital platforms economy. Touching upon the issue of optimizing passenger air transportation, we believe that the concept of omnichannel is relevant to the possibility of increasing the individual focus of air services. The ability to improve the efficiency of demand forecasting also plays an important role.

The practical contribution of the study includes representation of the workflow framework for a comprehensive digital energy efficient ommanichannel marketting informaiton system. This paper details review and developed mathemathical model based on the Porter, 1980, Porter, 1985 and recent studies Porter and Kramer, 2019. The paper contributes to and extends the existing understanding of digital multidimensional ommanichannel networking interaction to overcome on the marketting and future energy issues and conducting reasoning and derivation of mathematical formalisms for a limited channel dimension to show that the obtained relations are fully scalable and allow any increase in the number of interaction channels available in an actual situation.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Conceptualization & Writing, SEM and SMS methodology; VVP software; KKL; validation, TLK and AVK, drafting, edtiting, and reviewing. All authors have read and agreed to the published version of the manuscript.

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Assessing Multidimensional Energy Poverty and Its Economic Impact on N11 Countries: Mediating Role of Energy Efficiency

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This study seeks to estimate energy poverty using a multidimensional and wide-ranging category of indicators *via* the GRA-SRA approach. The study entails a case study analysis of the N-11 nations utilizing data from 2000 to 2017. Thus, a formulation of multidimensional energy poverty indexes of multidimensional indicators crosswise three dimensions is carried out. Energy availability, energy affordability, and energy cleanability, with regard to the N11 nations, are taken into account. The findings reveal that total energy poverty has progressed. We discover that Bangladesh (0.65) and Pakistan (0.47) are at risk concerning energy poverty, whereas the Philippines (0.36), Indonesia (0.33), and Vietnam (0.28) are less exposed to energy poverty. The relative changes in energy poverty are discovered among the N11 nations, where South Korea witnessed a consistent advancement in energy poverty, whereas Iran displayed a reduced trajectory and a vacillating trend. The findings indicate that the energy sources utilized for warming homes are essential within the scenario of energy poverty and inequality. Contrary to traditional steps, we assess the multidimensional energy poverty at the national level instead of the depths of gravity of energy poverty specifically for the energy-poor as against the whole population.

Keywords: energy poverty, GRA_SRA method, econometric estimation, N11 countries, economic conditions

INTRODUCTION

Energy poverty explains the inadequate alternative energy types and the appropriate circumstances to access energy adequately, affordably, in constant supply, in an uninterrupted manner, and through environmentally sustainable new energy services (Middlemiss et al., 2019; Chien et al., 2021a; Ehsanullah et al., 2021) which contribute to attaining economic and human advancement. The concept of energy security came from the fuel debate in the advanced nations, a situation where families or individuals do not have the energy to maintain their homes at an ambient temperature. According to the World Health Organization, the ambient temperature is 21°C in the hall and 18°C in

different rooms with AC. Seminal research by Betto et al. (2020) and Primc and Slabe-Erker (2020) defined fuel poverty as a situation in which the needed aggregate fuel costs are more significant than the national median fuel cost. If the house were to expend the same sum of money, the household's residual income would be less than what the government classifies as fuel poverty. In other words, people cannot derive and purchase sufficient levels of heat for their homes as estimated as a percentage of energy spending surpassing the upper limit of 10% of the nationwide median, to be a reminder of earnings, puts the household in the category of the officially recognized poverty line. That is the low-income–high-cost approach proposed by Hills (Moniruzzaman and Day 2020). The critical idea of energy poverty developed from the concept of fuel poverty approximated to be the situation of industrialized countries that have cold weather (Chien et al., 2022; Xiang et al., 2021; Primc et al., 2019; Okushima 2017). Fuel poverty scopes are limited because it considers only households that cannot keep their homes sufficiently heated as a result of costly plus aggregated fuel debts (Chien et al., 2021b; Xueying et al., 2021; Khanna et al., 2019). Contrarily, energy poverty is explained as the inadequate availability of power and clean cooking solutions to meet the basic energy needs of households (Tan et al., 2021; Acharya and Sadath, 2019). The study concerning energy poverty meaningfully examines the emerging nations with all manner of weather conditions (Sokołowski et al., 2020).

As a result, energy poverty has severe socio-economic consequences, including a decline in social cohesiveness due to a lack of social engagement and isolation. Research on energy poverty is necessary for the following four reasons. To begin with, no one can agree on measuring energy poverty, just as no one can agree on how to measure economic poverty. There are four main reasons why research on energy poverty is essential. There is no consensus on measuring energy poverty, apart from economic poor. In addition to the studies by Rogelj et al. (2013), a study of the benefits and drawbacks of multiple energy poverty measures is needed, along with a new technique for reconciling rationales. The scope and severity of the problem make it imperative that we examine the issue of energy poverty said that approximately one-fourth to one-third of the world's population lacks access to adequate energy. The third justification is based on the idea that identifying and addressing energy poverty should be the first step in solving the issue. For further information, see Middlemiss et al. (2019).

To put it another way, what can be measured can be controlled. Because access to energy is a means, not a goal, to economic growth, the fourth reason is fundamental. Water, sanitation, and education are all made possible because of energy, which powers the production of these essential products and services (Beto et al. 2020). In addition, energy has a multiplier effect on the output of activities that generate income in agriculture, manufacturing, and the service sector. It is expected (Primc and Slabe-Erker 2020; Huang et al., 2021a). The poverty meter, based on energy scarcity rather than earnings or wealth, is more relevant for policymakers and implementers of development plans because it enhances the lives of the poor and assures a steady supply of new energy services.

For this reason, the energy poverty terrain in emerging nations needs this examination, and so, our study presents the reference point by undertaking a thorough methodological literature analysis of pre-existing studies crosswise the emerging economies. This procedural analysis gives a full and wide-ranging impact size of energy poverty, elucidates the research to analyze heterogeneity in these impact sizes, and gives predicted sample figures concerning energy poverty within the set of circumstances (Castaño-Rosa et al., 2020b). As far as we know, no reference analysis or consistent examination that analyzes and compares various studies applying various approaches to estimate energy poverty existed previously (Scarpellini et al., 2019; (Huang et al., 2021c; Ahmed and Gasparatos, 2020). Thus, the variances in energy poverty approximate in the current literature create difficulty understanding it in literature analysis.

As a result, it is necessary to undertake a systematic analysis to derive a candid variable that approximates the energy poverty throughout the current literature for emerging nations. Next, it is crucial to investigate the seriousness of the issue for constructing effective policy decisions based on local conditions. Sub-optimum policy solutions might arise in the absence of precise evaluation and reference point analysis. Third, a limited scope might exist concerning the generalizable summaries about the proper impact size obtained for the evaluation of individual studies. Thus, to do a pooled assessment of the analysis of the current literature is a workable option to boost the proof of the advantages of recent research. Given this situation, the overarching aim of this research is to approximate a summary effect size estimate of energy poverty, analyze its originality using heterogeneity analysis, and find out the impact of varied casual factors on heterogeneity between the approximates of the study countries. Also, the research seeks to couple different methods to evaluate energy poverty.

REVIEW OF LITERATURE

These are some of the 11 nations that make up the N11 group: Egypt, Bangladesh, Iran, Indonesia, India, Pakistan, Nigeria, the Philippines, and South Korea. According to Goldman Sachs, these countries will become global economic giants in the next several decades. Because of their rapid economic growth, the economies of these nations might eventually reach or perhaps exceed those of the present financial leaders of the world. With that said, the N11 countries confront a wide range of problems in their efforts to acquire energy. Individuals in Nigeria, Pakistan, and Bangladesh are among the 10.1 million people who lack access to essential power services. However, households in several countries are increasingly investing in alternative energy sources such as standalone solar photovoltaic systems. According to our research on the N11 countries, the economically disadvantaged countries still face significant energy poverty. N11 countries have made tremendous progress toward ensuring that their citizens have access to low-cost renewable energy. However, the majority of the populations of these economies are still relying on fossil fuels for their daily needs despite the efforts of many N11

countries to increase access to affordable and clean energy and their current financing in modern renewable energy.

Pakistan provides less than 20% of the total energy supply of the N11 countries, compared to Korea and Vietnam's more than 30%. Sixty per cent of the population does not have access to electricity, and 40 per cent does not have access to contemporary energy sources; nevertheless, one-third of the population does have access to new types of energy for cooking. This lack of progress in finding new sources of energy consumption is a consequence of poor electrification and infrastructure for new energy sources. Additionally, 3.5% of the population is affected by extreme poverty. In 2017, the electrification rate in Indonesia was 95.35%, exceeding the objective of 92.7%. According to the World Bank, over 97.6% of the world's population had access to electricity in 2016.

Around 2014, nearly 60 million people out of the cumulative population in Bangladesh got access to energy. Within that year, the country had reported a national electrification mean figure of 62%, along with urban and rural electrification percentages of 84% and 51%, correspondingly. In the following year, 66% of people had been hooked to the grid. This implies that similar to the case of the nation's industrialization, Bangladesh would start to expand its generation resources to give electrification to the whole population. The government is lagging regarding energy supply, but it has advanced majorly in 2 to 3 years. Regarding the installed electricity capacity, Egypt's total installed additions were recorded at 21,423 MW in 2016, showing an expansion from 18,765 in 2015. Nevertheless, the energy supply per head was reduced.

Indonesia places higher in relation to power access and modern energy sources, with 97.7% of its population accessing electricity. Nevertheless, about 60% of the countries have access to energy sources for cooking food. Present data concerning energy consumption illustrate that Indonesia's energy consumption is the same as that of Japan, which is hugely self-reliant, whereas the total head energy supply is overly poor. While Iran is placed fifth amongst the samples of the study nations regarding electricity access, 96% of its metropolitan residents possess electricity coverage, and rural coverage is 96%. From 2001 to 2017, there has been a significant advancement in electricity coverage in urban areas of Iran. Likewise, when comparing Iran and Turkey and Korea, there is no significant difference between them.

In addition, Mexico is placed first amongst the sample of the electricity coverage of the study countries, along with 97% of its urban households having access to electricity. Nevertheless, like Iran, Mexico has several isolated islands that can pose a challenge to connecting residents there to the national grid. This restrains access to electricity in rural settings. When a household's per head earnings is less than the practice, the odds ratio for the "food refrigeration privation" clusters increases from 1 to 1.834%, whereas the odds ratio for the "food cooking privation" (83.4 expansion) (144.5%) category increases from 1 to 1.2.445 (83.4% expansion) (1.44.5% expansion). The truth is that nearly 8,900,000 Mexican house owners do not have access to one form of energy or another, about 3,900,000 households living in low or dire energy poverty, while the Philippines' energy structure per $1000 or gross domestic product is 2/3 of Japan, showing that the country is in an acute shortage of energy supply. Nonetheless, energy distribution has increased substantially in the past two to 3 years. Regarding electricity, the nation's total installed capacity had grown to 21,423 MW in 2017 from 18,765 MW in 2001.

Vietnam has witnessed a tremendously good performance regarding access to power plus other present energy source indicators. Nonetheless, the nation seems to lag regarding modern cooking fuels and technology coverage. They import fuel and natural gases from other countries irrespective of being self-reliant with regard to power. Generally, Vietnam did well, despite clean fuels for cooking and technology from 2001 to 2017.

DATA AND METHODOLOGY

Energy Poverty Indicators

The idea of energy poverty is complicated since it is affected by several different factors, which, in turn, interact and create further difficulties in a variety of real-world situations. Poverty is defined as the inability to satisfy a person's fundamental requirements, according to earnings-based poverty indices. A big worry is that it is seen as ineffective. The material difficulty index might be a valuable tool in the case of energy poverty. A person's income is an important consideration, but it is not the only one that matters looking at their energy poverty. It is linked to a person's wealth, and hence, energy poverty and health are linked.

Using the selected indicators, one may estimate one's level of energy poverty in various ways. Despite its lack of originality, this framework provides several distinct advantages. It has been proposed that European policymakers and shareholders use metrics proposed by the N11 Poverty Observation as a starting point. According to experts, these are the best ways to estimate energy poverty. Additional data back up redundant correlations and calculate specific energy poverty parameters in homes across the area. There was a 40% level of duplication found between the subjective and present variables. The deficiency characteristics were selected to cover a wide range of aspects of energy poverty while still providing relevant information. There is no need to take into account any other factors.

Multidimensional Energy Poverty Index

Currently, there is not a standardized way to measure energy crises; hence, various metrics are used. A quantitative assessment of energy poverty is necessary because of this. There are too many variables in the existing indicator evaluation approach to account for all aspects of energy poverty. Energy poverty can only be assessed using a single index due to the lack of available data. Because of this, an effective indicator system is needed to measure energy poverty. There are parallels between the effects of energy poverty in the N11 nations and those in other countries.

Consequently, the International Energy Agency's energy poverty index is relevant to all N11 countries. It is possible to duplicate the efficacy and cleanliness of home energy usage. In addition, Pachauri et al. (2004) devised a set of indicators reflecting China's current state of affairs, for example, energy

TABLE 1 | Threshold model analysis.

	Model_1	Model_2	Model_3	Model_4
AE < γ1	−0.0422*** (0.002)		−0.0298** (0.003)	
TRGE ≥ γ1	−0.315*** (−0.002)		−0.324*** (0.001)	
ANE < γ2		−0.235* (0.011)		−0.254** (0.005)
Gini ≥ γ2		−0.0911*** (0.002)		−0.184*** (0.003)
FREE	−0.0325*** (0.001)	−0.032 (1.022)	−0.013 (0.112)	−0.016 (1.111)
lnEPP	0.2112 (0.012)	0.432 (0.001)	0.432 (0.001)	0.462 (0.003)
Trade	0.421*** (0.001)	0.152*** (0.002)	0.263*** (0.001)	0.1321*** (0.001)
GDPEnU	−0.217 (0.259)	−0.348*** (0.208)	−0.214 (0.269)	−0.2320*** (0.209)
ACFTC	2.423 (0.352)	2.423 (0.454)	2.345 (0.387)	2.494 (0.322)
Observations	672	672	672	672
Constant	2.432 (2.036)	0.562 (2.654)	2.675 (2.111)	0.885 (3.665)
R-squared	0.488	0.454	0.465	0.653
Threshold value	2.21	0.76	2.65	0.86
Threshold test *p*-value	0.003	0	0.046	0

imports, energy supply investment, home electricity use, and cooking appliances. For this reason, we used both the GRA and the SRA methods to calculate a comprehensive measure of energy poverty. Due to the equal weighting of all exploratory elements in the situations considered in this research, Deng's GRA equation in its original version may be used effectively. Agyekum et al. (2021) Zhang et al. (2021) and Iqbal et al. (2021).

Assume that an ij represents a country's actual performance on indicator I during the assessment period j. This would be a reasonable assumption to make. An indicator's weight was estimated by considering its connection and the others in the multidimensional energy poverty index. There were higher weights given to the hands with the most vital relationships. It was also used to estimate the connection level during the weighing procedure, while sequential relational analysis was used to estimate the weight. A simple straight-line weighting method was then used to create an energy poverty index that included the consequences of the various variables. The category of baseline series to the performance of indicator I over n evaluation phases (denoted $A_i = (a_{i1}, \ldots, a_n)$) and the comparison series to the performance of indicator k is denoted as follows:

$$A_k = (a_{k1}, \ldots, a_{kn}); where\ k = 1, 2, \cdots m; k \neq i).$$

First, an objective SRA technique estimates the indicator weights based on the grey correlation. First, the SRA technique uses a relationship level comparison to determine the importance of indicators. Mean grey correlation degree ink is used as a crucial mid-variable to represent the indicator's significance. The following are the stages involved in implementing the SRA strategy.

Table 1 shows the factors related to socio-economic characteristics. Building a wide-ranging measure of energy poverty is possible because of this disparity and the variety of the underlying elements. The policy framework may be readily formulated using an energy poverty index since it provides a robust assessment of a broad range and a complete energy poverty index. Using a maximum probability technique, the STATA program was used to examine a Tobit equation and determine its significance. The MDEPI values range from [01], the most minor deficiency marks of which imply no energy poverty in any dimension, while the figure of one demonstrates more significant energy poverty in all aspects. As a result, to undertake an exact analysis, a limit Tobit equation is estimated, having the explained and exploratory variable mentioned above:

$$Y_{it}^* = \beta x_{it} + u_{it} \tag{1}$$
$$Y_{it} = \{Y_{it}^* - if - Y_{it}^* \geq 0$$
$$0\ otherwsie$$

where Y_{it}^* is the unobserved explained variable that has been applied in the analysis surrounded by a dual-censored *via* upper limit one and lower limit 0 0, u_{it} depicts the distributive stochastic term, I represents the observation, and t describes a time phase and x_{it} depicts the category of independent indicators for a formulated framework. β represents the vector for the variable of the coefficient. Any shortened observation can be characterized through MDEPI = $\{i\colon Y_{it}^* \leq 0 \cap Y_{it}^* \geq 1\}$. The approach for estimating measures the performance of the individual indicators.

$$\mathrm{I_i} = \sum\nolimits_{\mathrm{j=1}}^{\mathrm{N_{ij}}} \frac{1}{\mathrm{N_{ij}}} \mathrm{I_{ij}} \tag{2}$$

$$\mathrm{I} = \sum\nolimits_{\mathrm{i=1}}^{\mathrm{N_i}} \frac{1}{\mathrm{N_i}} \mathrm{I_i} \tag{3}$$

For each state, the number of indices for EPi is marked by $N_{ij}N_j$, N_i denotes the target quantity for which every provincial has data, and the mark of the indicator j inside EP is designated by I_{ij}. The rescaled indicator j score of the nation serves as a basis for calculating the EPi mark I_{ij}. It is necessary to calculate an EPi-wide goal index I_{ij}. EPi marks I_i are calculated using the arithmetic median marks of Iij for the whole province. Similar arithmetic mean is used for each zone to assess its effect, I.

Data Sources

The multidimensional energy poverty index of the N11 nations is assessed using the specified methodology. From 2001 to 2017, various indicators were used in the study (**Figure 1**). The

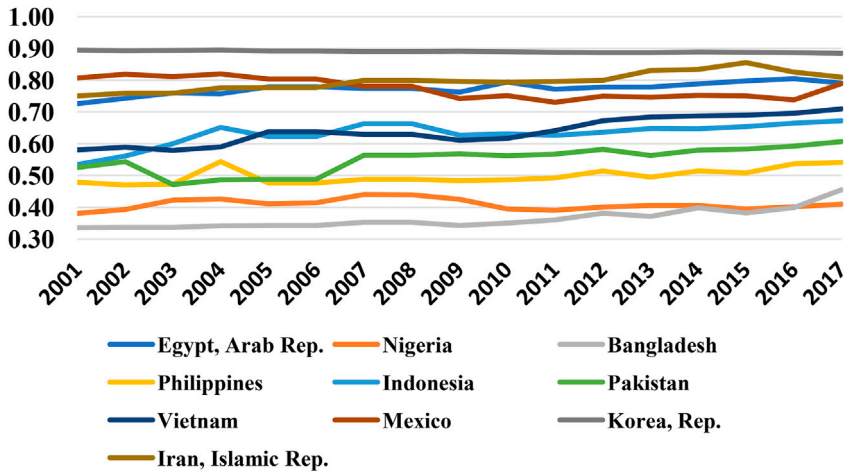

FIGURE 1 | Overall energy poverty index from 2001 to 2017.

following are the sources from which the data were obtained and information on the energy use of families. The International Energy Agency (IEA) provides data on home carbon dioxide emissions and energy usage.

RESULTS AND DISCUSSION

Overall Multidimensional Energy Poverty Index

The comparative multidimensional energy had reduced at a mean yearly rate of 4.19% from 2001 to 2017 and 2.46% from 2001 to 2008, as well as 0.88% from 2009 to 2017. This implies that the general energy poverty has been advancing over time while the advancement slowly slows down since the 2008 financial crunch. Additionally, significant differences in energy poverty are found within N11 nations. Concerning Nigeria, Bangladesh, and Pakistan, the comparative nearness slightly increased from 2012 to 2017. At the same time, Egypt and Mexico revealed significant variations within the previous years. Similarly, South Korea constantly advanced in energy poverty from 2001 to 2017. Nevertheless, Iran witnessed a reduction trajectory along significant variations occurring from 2001 to 2010 before the country's energy poverty stayed reduced around 2001 to 2017.

The gross domestic product expansion is anticipated to be lowered by 6.2 and 8.2 points, providing increases to a budget and the current account increasing deficits integrated with inflation that is more than what was initially forecasted (AfDB, 2020). The actual gross domestic product rate will be reduced by 2.3% in 2020 as the pandemic lasts beyond the first half of 2020 and will deteriorate to 4.2% if the pandemic continues up to December (AfDB, 2020). The nation's economy has an inadequate diversity and depends significantly on the primary sector that is dominated by mining. The Gini coefficient for Nigeria is exceptionally high for the nation. This elucidates the disproportionate distribution of income within the government. The nation's riches are equally shared by the population, where nearly half of the population has different income distribution. This is so because a more significant Gini coefficient translates to an inconsistent distribution of income.

Econometric Estimation of Energy Poverty

This part discusses the correlation amongst the number of indicators in defining the direction and the scale of the coefficients, along with explained and experimental parameters which describe the extent of the energy poverty index at the country-level hands. Moreover, instances that result in short-term closure of businesses such as cyber cafes, which rely mainly on the power energy to run their operations, limit the potential income realized from the services they offer to the consumers in the market. Similarly, when power fails in a particular sector of an economy, it creates a vacuum that leads to short-term unemployment for the individuals relying on energy to conduct their daily economic activities. Therefore, the issues associated with energy poverty across most N11 nations cause an inevitable shortage of production and innovation opportunities, eventually leading to high unemployment rates.

The findings show that all indicators described in **Table 1** are negatively linked with the multidimensional energy poverty index. This implies a unit variation in access to electricity as an alternative, and nuclear energy decreases energy poverty by 0.058 and 0.128 times, similar to the energy consumption and energy use reducing energy poverty to 0.61 and 0.34, respectively. Deductions from the heterogeneous yet correlated studies and outcomes can be made appropriately with meta-regression analysis (DerSimonian and Laird, 1983) to shed more light on the heterogeneity between the impact sizes.

Table 2 illustrates regression results. Tobit regression findings for multiple indicators and the energy poverty index reveal that access to electricity, periods needed to get power, investment in energy alongside private participation, access to clean fuels and technologies for cooking, and the poverty headcount ratio are directly meaningful at a significance level of 1% ($p < 0.01$). Furthermore, gross domestic product per component of energy

TABLE 2 | Results of the Tobit regression model.

Indicator	(1)	(2)	(3)	(4)	(5)
	EPI	EPI	EPI	EPI	EPI
(Intercept)	−0.322***	−0.2015***	0.137***	−0.815***	−0.287***
AEP	0.013***	0.0334***	0.0162***	0.028669***	0.0130***
TRGE	0.1867***	0.14343***	0.117***	0.61082***	0.9890***
IEnPP	−0.2261***	−0.2556***	−0.06483***	−0.11271***	0.012***
ANE	0.79264*	0.25839**	0.9845	0.54662*	0.131652*
EnI	0.1056	0.62656	0.1164	0.1867	0.6976
EnU	0.0456	0.02665	0.0590639*	0.2543	0.0475
FFEC	0.184012**	0.938114*	0.1002*	0.4467	0.199214*
GDPEnU	0.218876	0.22667	0.32453	0.2235	1.0267
REnC	0.59366	0.7265	0.3378	0.1764	0.4264
ACFTC	0.8334***	0.16654***	0.271***	0.412***	0.03176***
EnILPEn	0.56894	−0.16665	−0.1175	0.2753	−0.7367
PoHR	0.7562***	0.109***	−0.373***	0.0838***	0.13882***
Gini	0.19567	0.38654	0.2564	−0.285	−0.0167

TABLE 3 | Results of robustness analysis.

Indicator	(1)	(2)	(3)	(4)	(5)
	EPI	EPI	EPI	EPI	EPI
(Intercept)	−0.322***	−0.2015***	0.137***	−0.815***	−0.287***
	(0.003)	(0.004)	(0.004)	(0.003)	(0.002)
AEP		0.0334**	0.0162***	0.028669***	0.0130***
		(0.007)			
TRGE			0.117***	0.61082***	0.9890***
			(0.002)		
IEnPP				−0.11271***	0.012***
ANE				0.54662*	0.131652*
				(0.005)	
EnI					0.6976
					(0.024)
EnU					0.0475
					(0.054)
FFEC					0.1994*
					(0.006)
GDPEnU					1.0267
					(0.032)
REnC					0.4264
					(0.032)
ACFTC					0.0317***
					(0.004)
EnILPEn					−0.7367
					(0.021)
PoHR					0.13882***
					(0.002)
Gini		0.38654			−0.0167
		(0.165)			(0.0231)

use is adversely associated with the energy poverty index at a significance level of 5%.

Robustness Analysis

In this part, we conduct robustness testing to assess the sensitivity of our findings. Our original estimate of energy poverty is based on a dummy parameter with an upper limit of 10% on the percentage of earnings spent on energy. Some research suggests that a maximum of 10% may be too low. We test the sensitivity of our results to several cut-off points, such as 5%, 115%, and 20%, to make sure they are unaffected by the cut-off. As it turns out, the upper limit we used to explain the estimate of energy poverty did not affect our results whatsoever.

Findings evaluating the influence of several methods of assessing ethnic differences emphasize the direct link between ethnic diversity and energy poverty. Ethnic polarization indexes are used more often than Herfindahl formulae to estimate ethnic disparities. We find that rural energy availability's polarization-estimated effect is direct and consistent across all columns. The standard deviation rise in ethnic polarization is connected to a 0.100 standard deviation increase in the share of earnings spent on energy in column one. In column two, we find that an increase of 0.030 standard deviations in the number of families spending more than 10% of their income on energy is associated with an increase in the standard deviation of energy affordability. Column three's results also suggest that an increase of 0.0015 standard deviations in the number of families unable to warm their houses in prior years is connected to an increase in the standard deviation of energy availability.

Table 3 presents results using these alternate upper limits. These data demonstrate a statistically substantial influence of ethnic diversity on energy poverty in column two but not in columns three and four. In column one, we observe that a standard deviation development in energy access is associated with a 0.062 standard deviation increment in the share of family wages squandered on energy. Likewise, within column two, the data suggest that an ordinary deviation gain in energy access is connected with an increment of 0.0034 standard deviations in the number of families who spent more than 10% of their incomes on energy.

Average Household Electricity Consumption

Accessibility of electricity across many nations in the N11 regions is affected by various aspects, including cost of electricity, limited infrastructures, sub-standard housing structures, low electricity generation capacity, and unexploited energy harnessing approaches. The cost of electricity is a potential factor that

TABLE 4 | Average household electricity consumption (kWh) per day.

Domestic portable appliance	Length of use	Capacity watts used	kwh/consumption/year	kwh/consumption/day
100 W light bulb	4 h/day	100	146	0.4
Fan–ceiling	5 h/day	175	159.25	0.44
Fan–window	5 h/day	250	227.5	0.62
Fan–furnace	5 h/day	750	682.5	1.87
Fan–whole house	5 h/day	750	682.5	1.87
Water heater (40 gallon)	2 h/day	5,500	4015	11
Water pump (deep well)	2 h/day	1,100	803	2.2
Combination fridge–freezer (a)	365 days	A+	190	0.52
Combination fridge–freezer (C)	365 days	C	500	1.37
Microwave oven	1.5 h/week	1,000	60	0.16
Iron	4–5 h/week	2,800	582.4	1.6
Washing machine	3 h/week	2,200	343.2	0.94
Laptop	3 h/day	100	109.5	0.3
Mobile phone charger	2 h/day	12	8.76	0.02
Kettle	3/week	3,000	468	1.28
Radio	2 h/day	40	29.2	0.08
Hairdryer	3 h/week	2,200	343.2	0.94
Computer monitor	3 h/day	100	109.5	0.3
Desktop computer	3 h/day	700	766.5	2.1
Television	4/day	120	175.2	0.48
Toaster	1.5/week	2,000	156	0.43
Radio (stereo)	2 h/day	400	292	0.8
Total			10,849.21	29.72

Source: Authors' recommendation.

lowers the tendency of the members of the public to access adequate energy to run both household and industrial needs. Most households in N11 countries spend a large amount of their incomes to pay for the unaffordable electricity bills. Additionally, low exploitation of the possible energy generation approaches inhibits realizing the universal electrification goal across the N11 nations.

Kilowatt-hours (kWh) as shown in **Table 4** for the most typical residential appliances (KWh). According to figures from the United States used 10,399 kWh of energy every year, or 867 kWh per month. There was an average residential power use of 28.9 kWh per 867 kilowatt-hours-per-month. According to Eskom statistics, the average daily usage of a typical American family exceeds 30 kWh (kWh). Energy-efficient appliances are a fantastic method to lower the amount of power used in your home. In addition to air conditioners, electric fans are a standard method of cooling down a house. The daytime temperature in Badong city is 32°F, making it a sweltering place to be. People are more likely to utilize electric fans when the lack of natural ventilation is combined with high temperatures. According to the poll, two or three fans are common in most homes.

In addition, residents in N11 regions are forced to live in a unique confluence of social and environmental injustice because they lack access to adequate energy. Energy poverty is a socio-economic injustice that robs individuals of their livelihoods by limiting their ability to heat, cool, and clean their homes and workplaces. Due to energy poverty, Pakistanis live in environmentally awful situations such as low-quality housing, which exposes them to environmental threats and limits their capacity to raise capital to change their position. The vast majority of individuals are affected by price fluctuations in the cost of power and must devote a more significant portion of their income to paying for their electrical needs. Power companies force people to use pre-payment meters when the cost per unit is higher than what can be paid for in other ways. In the vicinity of N11 countries, similar findings were made. Renewable energy sources like wind and solar power might be vital to overcoming poverty, sustainably boosting economic activity, and combatting climate change in this context.

Discussion of Findings

Including the non-poor in the standard calculation of energy poverty depth and severity results in incomparable dilution levels for a nation with 46% energy–non-poor residents in urban areas. As a result, the estimates for energy depth and profound energy deficiency are more significant than those for the whole population. In their absence, the fresh estimates reflect the dire straits the energy-poor find themselves in. According to the new assessment, the depth and severity of energy poverty are far higher than the conventional data suggest. For the total urban population, the same results may be found. According to new estimations, the depth and severity of energy poverty in urban Uttarakhand are far more than in urban Bangladesh. Urban areas have a higher percentage of energy-poor individuals, but their degrees of poverty are far more severe in terms of the depth and severity of energy poverty. Energy–non-poor people do not contribute to the total or square of the energy poverty gap since they do not rely on inefficient fuels. Non-poor people, however, have a greater gravitational pull on the median depth since they make up most of the entire population.

On the other hand, energy poverty indicators do not take into account actual energy usage statistics at a certain point in thermal comfort. Those whose income is less than 10% of the cost of providing them with appropriate energy services are included. In

addition, a household is in energy poverty if its total earnings are less than 55% of the population's median wages. For this indication, they spend more on energy than the average family does (discounted housing expenditure and equal modeled energy expenditures).

In addition, because of the concept's multifaceted structure, as previously indicated, the relative inconsistency of the indicators may be highlighted since the statistics fluctuate according to the criterion picked. Consider the goal of eliminating energy poverty using energy plans that advance the stated element over a medium- to long-term time horizon. To sum up, the current energy situation in these isolated locations is relatively similar to that in the past. In addition, the scale of environmental energy poverty is alarming. Consequently, it is critical to analyze and collaboratively address existing energy planning objectives throughout the medium to long term. Instead of relying just on Band-Aid solutions to the problem of energy poverty, policymakers should focus on long-term solutions. They can reduce the inefficiency of the existing combination of power generation by decreasing risk and lack of diversity in this way. A more efficient energy production system might be created by including natural gas in the mix. Renewable energy (RE) output should be expanded to have more than only wind and solar power.

CONCLUSION AND POLICY IMPLICATIONS

Using the N11 countries as the study unit, our research calculates the energy poverty index based on many underlying factors. Data from 2000 to 2017 are included in the study. The dimensional energy poverty index was developed to rate the 11 countries in the research. The findings show that financing energy with private participation is consistently a significant negative factor in the energy poverty index, with extreme poverty-poor, moderate energy poverty, and transitional energy poverty, respectively, accounting for 3.2%, 26.3%, and 44.3% of the urban population. The N11 countries, in general, have a higher prevalence of energy poverty than the smaller ones. As a result of these findings, it may be concluded that those who cook and those who light their homes suffer from energy poverty. People who do not have access to contemporary lighting fuels are more inclined to go without modern cooking fuels. This reveals the need for cooking as a more fundamental requirement. The country's per capita energy usage is relatively low at 139 kWh compared to the world average of 31,104 kWh per head. Despite this, almost 80% of the total population lives in isolated villages far from the country's main transportation arteries.

Each area has its unique characteristics. Millions of people live in poverty, and energy poverty is both a cause and a result of that poverty. This circumstance necessitates the active involvement of all stakeholders in drafting energy policy to reduce poverty. However, this is not possible because of the procedures established to deal with short-term problems to produce quick, if momentary, results due to the political structure. The GRA technique employing the gray relational approach calculated 0.658 for energy poverty, 0.609 for energy availability, and 0.53 for energy cleanability. According to a new study, energy affordability was shown to have the most association with energy poverty, followed by energy availability and cleanability.

More than 40% of the people in Bangladesh, Pakistan, Nigeria, and the Philippines, all of which are part of the N11, rely on wood for cooking. This means that the socio-economic and geographic variables must make quick decisions to improve the family's economic standing and the availability of contemporary energy appliances, educational resources, and domestic technology. Wood, seasonal crops, and straw are the most popular cooking fuels that contribute to indoor air pollution, particularly for women. 22% of Bangladeshi people, 25% of Nigerians, 36% of Pakistanis, and 36% of Filipinos utilize liquified petroleum gas for cooking meals. Liquefied petroleum gas is used by 23.8% of Indonesians, whereas electricity is used by only 2.7% of the country's households. The average house uses about 10,649 kilowatt-hours (kilowatt-months) of power each month. A wind turbine rated between 5 and 15 MW is needed to meet this demand.

To better understand the relationship between family income and electricity use, we also looked at the discrepancies in household incomes and energy consumption. Although gas, oil, and energy expenditures had grown, the minority invested more diminutively than the majority group. In addition, the progressive growth in electricity and natural gas use may efficiently replace traditional high-carbon energy, hence reducing energy poverty.

Policy Implications

According to those mentioned earlier, we provide the listed policy implications under.

1) Our initial findings imply that no global policy can manage the problem of energy poverty. Nevertheless, the refreshing news is that acknowledging different pathways ensures greater flexibility in selecting the appropriate procedures. We also propose effective energy policies. Therefore, future research should continue looking into the data and methods to monitor energy poverty closely.
2) Our key concern is that giving priority to any policies might slow down the energy transition to a future with sustainable energy. Thus, we ask scientists to not only further evaluate the energy poverty phenomenon but to participate in crafting an effective policy regime equally.
3) In addition, policy formulators and indigenous politicians will discover it to be less difficult to respond to clear public stated goals and desires in achieving certain developmental goals; this can away political correctness. CSOs, auctioneers, and applied researchers can build a coalition toward a particular purpose to unlock energy poverty alleviation, resulting in extra organized boosts on policy instruments for results. Estimating energy poverty forms part of an opportunity to leverage actors and organizations and shape a more public responsible energy sector. The participatory undertaken act of measurement is important

as a metric concerning the objective of energy poverty alleviation.

4) Ultimately, the findings reveal direct coverage gains to electricity to multidimensional energy poverty in N11 nations. Within the short term, though, educational campaigns that improve awareness of the health, environmental, and economic costs and impacts of biomass reliance and indoor air emissions should be increased and maintained, particularly in communities and rural settings. Such educational and awareness creation programs should focus on driving behavioral change that encourages the energy transitions to current and RE sources as the better use of energy.
5) Despite the increased electricity accessibility across the region, many individuals still face challenges paying their energy expenses, thus limiting the benefits accrued from the electrification process in the region. Recent research revealed that the cost of clean and healthy energy in N11 nations is higher than that in the other regions across the globe; thus, the unaffordability of the energy limits most households from accessing regular electricity supply in the N11 countries. Using expensive resources to generate and distribute electricity across the population increases the eventual cost burden to the end-users. High taxes charged on the electricity supply across most N11 nations impose inevitable costs translated to the end consumers as the unaffordable energy cost across most households. Moreover, taxes on electricity generation and distribution processes across most regions' economies impede access to high-capacity electricity across firms to conduct extensive production processes. Similarly, high energy cost across most firms inhibits the effective creation of more opportunities that can be exploited by the high unemployed population across the N11 countries.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

MPH: Writing - original draft. K-TW: Conceptualization, Writing - review & editing KK: Visualization, Data curation. LT: supervision. TQN: Methodology. TTN: Software.

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Nexus Between Equity Pricing Models and Equity Price Fragility: Empirical Insights From Pakistan

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Purpose: The study tests conventional and behavioral pricing multifactor impact on price fragility from the equity market of Pakistan.

Methodology: The positivist approach is used to deduct study rationale via probability sampling. At the same time, systematic sampling for data collection of PSX is tested in parallel to mean-variance random walk theory.

Findings: The impact of conventional factors is significant on price fragility in the short run and vice versa in the long run. Specifically, herd behavior and disposition effects are found to be insignificant. But size, value, illiquidity, and price earning had a significant impact on price fragility in the short run.

Limitations: The current research has not covered the desired scope of the topic due to time limitations, lack of harmony in corporate data on databases, and literature on price fragility being very scarce.

Implication: In PSX, there is a need to develop a corporate culture to promote the standard modern financial practice to enhance financial productivity and sustainability. For corporate culture to be established, corporate governance boards should be established, and family governance systems should be replaced by an independent democratic board. Mispricing and arbitragers need serious control.

Originality: The value of the research is that little research currently exists on about pricing multifactor impact on price fragility.

Keywords: equity price, price fragility, conventional, behavioral, systematic sampling

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INTRODUCTION

The impact of finance is increasing day by day, and it has become a well-established discipline of study resulting in sound concepts formed from testified and rigorous theories (Cox and Britten, 2019). Thus, modern finance is now categorized into two sub-subjects: traditional finance and behavioral finance. Traditional finance covers activities performed in real financial markets and their interpolations and financial motives in a rational way. Behavioral finance talks about behavioral activities in financial markets and behavioral interpolating financial motives through rational

criticism (Coşkun et al., 2017). These domains are globally adopted, and their subject matter has relevancy in financial market practice. These subject equity funds and their prices are primarily based on the price mechanism. Therefore, it is highly valued and is still emerging in Pakistan due to the various responses of investors to the stock market (Rugwiro and Choi, 2019). Moreover, the participation of the Chinese economy in the Pakistani stock market is increasing, playing a dynamic role in equity price that would speed up in the near future (Jareño et al., 2020), and various other local micro factors will also contribute. Another reason for valuing equity price structure is the growth factor of P.S.X. In Pakistan, CPEC is causing a perceptual growth sentiment in the Pakistani economy *via* Chinese economic participation (Mosoeu and Kodongo, 2020). Moreover, China has shown its participation in P.S.X, especially in exchange traded equities. Recently, in Pakistan, third democratic transition phase has been working on building an institutionally sustainable sentiment backing the perceived sentiment of growth in the Pakistani economy (Fama and French, 2017).

The equity market integrates to the proper dispensation of ownership of equity funds and determines equity returns. A market is termed an "efficient market" where an investor invests randomly by capturing entire statistics upon stated market interpolated returns (Foye and Valentinčič, 2020). Such historical returns and investing trends are important information for an efficient equity market in forecasting expected capital gain to dispense ownership of equity funds (Ishtiaq et al., 2019). Moreover, the expected capital gain is co-integrated with variations in equity returns (Fama and French, 2018) and grounded by investor reaction to market statistics as exaggerated or understated. However, these contrary market statistics construct trading problems, informational ambiguity on the minor level, and joint hypothesis problem on the major level, as opposed to considering a market as efficient and testing efficiency with an assets pricing models (Lin, 2017).

The assets pricing models are the factors that capture fair value or returns of equity funds in a market. Thus, in a cross-section of the European context, size and market models of particular funds are well-explaining equity returns (Zhou and Li, 2016). And these are associated with procedural trends of equity growth and profitability factors. Extended to it, Belimam et al., 2018 found growth of sales and short and long-term returns as common variations participating in explaining size, value, and book to the market premium of asset pricing factors. Such findings are relevant to equity funds because these are found to be less explained and negatively associated with inflation (Fama and French, 2020). And it is best explained by arbitrage pricing theory (Karp and Van Vuuren, 2017), which has two discretions i.e. arbitrage factor and expertly diversification of portfolio.

Thus, these portfolios accurately explain pricing models with their size captured by market capitalization of a portfolio, value premium as high returns, and momentum. However, it is confirmed that pricing factors are heterogeneous, i e. Japan has less momentum in its market returns due to market spread and group size (Arora and Gakhar, 2019). Stock returns, meanwhile, are best explained by size, value, and market premium in Eastern Europe equity markets. But momentum insufficiently explains equity prices (Danielson, 2003). However, these market and volatility trends determine stock return by a five-factor model—value, size, market, and illiquidity premium are proposed, resulting in significant contribution in equity returns determination under contextual heterogeneity. This model is applicable in Japan, Portugal, and Pakistan.

Thus, it reveals the importance of these factors in equity funds investment, equity prices, and earnings.

Moreover, equity holders are ultimate resource holders. Equity risk shows risk preference behavior in equity allocation decisions (Habibah et al., 2021), resulting in the momentum of a new sixth factor of equity pricing (Liammukda et al., 2020) entirely failing to cover consumption-oriented reasons of equity investors in the equity market. These reasons explain traditional pricing factors and behavioral aspects i-e confidence and optimism in equity pricing or return determination, extending herding behavior and disposition effect in a rational market. Herding behavior is a psychological attitude among equity holders following similar investing or speculating patterns in equity funds within the same set of markets, portfolios, or groups and is found present in the Asian context (Gregoriou et al., 2016). It is less common in the Indian national stock market. Herding behavior in Karachi stock exchange was conditional because equity investors in K.S.E are price-conscious in the short-term in line with pride and regret graph line building following a dimension named as disposition effect (Gregoriou et al., 2016). However, disposition effect and herd behavior constructing equity investor's sentiments have diverse causal association with P.S.E volatility, affecting downside risk in long run (Chakroun and Hmaied, 2019) shuffles assets pricing indicators performance (Ahmed et al., 2019) drives market trading in non-fundamental side resulting extensively changing equity holding ownership (Afroz et al., 2020; Barua et al., 2020; Dai and Yin, 2020; Nwankwoala et al., 2020; Gao et al., 2021) and (Xiang and Qu, 2020). Thus, the severe presence of price fragility behind these reasons results in non-speculative bubbles, leading the equity market to crash.

There is less uniformity in the equity price structure of stock markets due to contextual variations where pricing factors work with high volatility. And such growth, social and political sustainability, and participation in the Chinese economy is also affecting the price structure of equity funds in Pakistan. Truly, the perception of these factors is positive in Pakistan theoretically, but in PSX, for a few decades, random walk is highly observed in market trading—based on various behavioral anomalies deviating trading mechanism of PSX from fundamentals to the non-fundamental side that creates price fragility. These sentiments have a high arbitrage influence on market trading, affecting equity prices negatively for two reasons: 1) external shareholders being well-informed individuals holding a majority of shares and are less actively participating in PSX but having a majority of share proportionate and losing their corporate earnings and multiple scores in comparison to international business concerns; 2) Most of the listed companies in Pakistan are limited companies with unsound corporate boards and unspecified long-term objectives; 3) As a

result, general/minority shareholders are speculating their trading on the daily market price to have returned and has become short term by responding less seriously with annual corporate dividends and reinvestment plans that maximize their capital gain.Thus, to tackle these inherent reasons against pricing mechanism and factors, we aim to resolve these reasons and their consequences on the prices of equities in PSX under random walk behavior.

The objectives of the research are as follows:

1) To test the traditional pricing proponents of equity funds.
2) To locate and test multifactor pricing models consisting of conventional and behavioral antecedents.
3) To identify and test the contribution/association of multifactor pricing models in equity price fragility.

On the bases of the study scope, we have segmented equity pricing theories into two categories: Neo-Classical pricing theories and behavioral theories. Such segmentation is planned to cover both conventional and behavioral dimensions of equity prices. For recent investigation, from neoclassical theories to the conventional aspects of pricing factors, theoretically, general equilibrium theory, mean-variance theory, and arbitrage theory address the issue of random walk-in pricing of equity funds. Moreover, to support behavioral aspects of this research, limits of arbitrage theory and behavioral theories are supporting the study investigation. As far as a general theory of equilibrium is concerned, it describes how equities price up the nature of procedural risk with the notion of "high return Vs. high risk". This theory has its scope from single-factor pricing to multifactor pricing. But Harry Markovitz extended this interplay of risk in 1952 by mean-variance theory and has said that there is an interplay between risk and returns because market investors are rational but risk-averse individuals. Hence, they are followers of mean-variance behavior in trading. There is a limitation in mean variance theory in that it deals with only risk assets. So, Ross challenged it in 1977 by proposing Arbitrage Theory, suggesting that equities are valued by multifactors instead of one factor, and the sensitivity of these factors is highlighted by their beta coefficient. Moreover, rate of return of the portfolios accurately defines assets prices and if the prices ramify then the arbitragers will recover it.

On the side of behavioral aspects, limits to arbitrage theory covers pricing of equity funds that the arbitrage limits that would often be used by rational investors but the price may work in a limit of protection in a non-equilibrium position. This theory further explains that when dealing with noise traders, a shift in equity prices prevails, and prices are prone to misprices where a rational investor is found helpless to eradicate it. Similar conditions for arbitragers also exist. So, to elaborate on such phenomena, scholars turned to the behavioral side and have revealed that there are certain preferences and attitudes in trading and market prices. So, to address this preference-oriented behavior, there is a need to study another behavioral aspect where various sentiments of investors as associated with equity trading activities negating efficiency, mean-variance, and equilibrium of equity tradeoffs. Hence, the idea of merging behavioral aspects of investors with equity or equity price cannot be removed and it has its own unique representation with classical finance.

The study will contribute theoretically on several sides. Firstly, it will locate the equity pricing factors in the Pakistani context. Secondly, this research will contribute to work on the random walk behavior of PSX and cover historical and contextual reasons. The study will contribute by assessing equity pricing factors by conducting an interdisciplinary study on conventional and behavioral finance—rarely conducted on pricing structure in any context with multiple dimensions of random walk behavior to extend the theoretical ground of random behavior in a conventional market.

We also propose a new factor contributing to the equity pricing system that will add new addition in theoretical grounds with six factors of equity pricing that are well deducted. We will also contribute a new dimension of conventional pricing factors by working with context-specific research on equity prices and price fragility. In practice, single digit studies are found by Acharya and Viswanathan (2011) for three and four-factor pricing models. Only one study is found on five factor models of equity prices. This study will work as an extension of such previous Pakistani studies as extending to seven factors of equity pricing with a new dimension. Moreover, assessment of these factors with price fragility is not found in previous literature. Finally, this research will suggest the best fit model for the Pakistani stock market on the bases of random walk behavior for assets pricing and will also suggest the reasons for the fragility of equity funds prices with the contribution of these pricing factors. So desired policies could be made to overcome random behavior and boost productive consistency in equity prices of PSX.

Part one is explaining the topic, background, issues to research, and objectives. Part two incorporates the overview of the literature of asset pricing framework, various models developed, and proposes a hypothesis. Part three deals with data description and methodology. Results are given in part 4. Part five and six are about discussion, findings, and recommendations.

LITERATURE REVIEW

Stock price fragility was initially introduced by Jin-Li and Shih-Chuan, 2006. It measures non-fundamental risk. Thus, it aims to segregate and measure the causal effect of stock volatility beyond the traditional financial measures, specifically examining the concentrated stock ownership and correlated liquidity shocks on price volatility. So, these measures would be applied in the Pakistani market. This investigation can be extended to the entire globe because it has a wider room available geographically that has not been much investigated. Moreover, by extending the investigation of fragility it would be explored by checking covariance and beta of returns by co-fragility and fragility beta in the current investigation. Hence, the previous investigations

suggested that ownership structure has an impact on these forecasts. Finally, fragility is also suggested to interact with total return volatility to have an impact of arbitragers on stock prices and it is found to be significant in an African context. Such contextual effect of volatility is another main factor that affects stock returns, including other market motives and sentiments i.e. herd behavior, disposition situation, and news effects. These behaviors and sentiments follow the trends in quantified shape rather than the movement of trades. To quantify these movements in market prices there is a need to design market segmentation in trades and trading products. This segmentation in products raises firm expectancy of life that enhances book to market value of the company and it has a sound relation with price fragility. But such life expectancy varies over time and it has diverse consequences on various equity natures that break the momentum of assets prices (Sarwar et al., 2020).

The crash of momentum results inconsistently in the working of five factors of assets prices in equity market. Moreover, these five factors (size, value, momentum, illiquidity, and market premium) have best explained the variation of portfolios in the international world. Similar findings have been found in China (Lin, 2017). Moreover, in north America and Asian countries, five factors accurately explain their role in market prices, causing fragility, but in Japan, momentum is not working significantly due to market inconsistencies. However, these inconsistencies are due to firm-level decomposed sensitivities that float fragility in market prices of equity funds. And it leads to arbitrage behavior in market prices—another reason for price fragility.

We present the following hypotheses

H1: There is a significant impact of size premium on price fragility.
H2: There is a significant impact of value premium on price fragility.
H3: There is a significant impact of momentum on price fragility.
H4: There is a significant impact of illiquidity on price fragility.
H5: There is a significant impact of price earnings premium on price fragility.
H6: There is a significant impact of market premium on price fragility.
H7: There is a significant impact of investor sentiment on price fragility.

RESEARCH METHODOLOGY

The ontological framework of the study is to assess the multifactor of equity pricing and its impact on stock price fragility. The intent to assess such factors on price fragility is to locate conventional and psychological factors working in a standardized market to understand their nature and influences. The epistemological posture of our research is positivism that the developed knowledge has a singular reality due to specified contextual reasons of randomly mean variant less arbitrage behavior in the Pakistani stock market. And the (He et al., 2020; Mohsin et al., 2020; Yang et al., 2021), the research is formal. The approach of the study is deductive. The study aims to test random walk behavior via mean-variance and limits to arbitrage approach in PSX. Such a deduction is conducted on recent data of PSX and will discuss implications relevant to it (Sun et al., 2019) and (Tiep et al., 2021).

The study is explanatory in kind about price fragility and multifactor equity pricing; we have used a positivist approach to go deeper towards PSX realities and to deduct their proper direction. Choosing this rationale involves several aspects: 1) stock market investors are complex and multifactor cases, prioritized by the positivist school of thought, based on the hypothetico-deductive approach of investigation incorporating quantitative method to generalize findings; and 2) In Pakistan, investors are trading sentimentally, which has been less highlighted in previous research and is still under research in this region.

By adapting the positivist approach, probability sampling technique is deployed. Moreover, a systematic sampling technique is used for sample selection and representation. We used systematic sampling to represent the true scope of this research by capturing high leverage, more sensitivity, and reasonable liquidity. To obtain the sample systematically, we have designed the criteria to select the stock that remains listed in PSX for more than or equal to two quarters of the year during the sample years of analysis. The population of the study is listed stocks at P.S.X. This research uses monthly data of listed stocks in P.S.X from 1/2008 to 12/2017 with the discretion that, during this period, continuously listed stocks are incorporated for analysis, having at least two quarter liquidity period in market. Stocks of non-financial counterparts are selected as a sample of analysis. The data is collected from the online source of PSX (psx.com.pk & ksestock.com) and opendoors.com. The data is time series in nature and out of 100 indices thirty-seven companies are selected for analysis as per selection criteria. These companies consist of healthcare, Oil & Gas Marketing, Oil & Gas Exploration, Cement Sector, Fertilizers, Banking Sector, Telecommunication, and Electrical sectors. As per the selection criteria, sector-wise representation of companies is heterogeneous in nature because a few companies did not meet research criteria and a few sectors have only one company and meet the criteria of selection.

The new factor is investor sentiment that is computed by developing a sentiment index comprised of three conventional proxies i-e stock market turnover, dividend premium, and equity shares with two behavioral proxies as herd behavior and the disposition effect. So, we have factorized seven factors: size, value, momentum, Illiquidity, market, PE premium, and sentiment premium. Moreover, we have selected six portfolios meeting data selection criteria for analyses. To check the factorial exposure of portfolios, we created a *t* time and to sort these six portfolios, calculated them on *t-1* June of year. These are formed named as $\frac{S}{H}, \frac{S}{M}, \frac{S}{L}, \frac{B}{H}, \frac{B}{M}, \frac{B}{L}$

$$\text{Size Premium} = \text{SP} = \frac{1}{24} X \left[\frac{S}{H} + \frac{S}{M} + \frac{S}{L} + \frac{B}{H} + \frac{B}{M} + \frac{B}{L} \right] \quad (01)$$

TABLE 1 | Descriptive analysis.

	PF	VP	SP	PEP	MP	MOM	ISP	ILLQ
Mean	1.393	0.865	117.3	2.3	139.3	193.3	0.22	943.1
Median	0.004	0.880	113.2	2.3	133.3	233.3	0.37	841.3
Maximum	45.599	1.450	731.3	4.6	406.9	457.9	62.6	17.5
Minimum	0.000	0.078	39.9	0.2	5.3	2.05	-92.2	44.4
Std. Dev.	7.220	0.188	36.5	0.9	89.6	9.6	13.2	48.4

$$\text{Value Premium} = \text{VP} = \frac{1}{08} X \left[\frac{S}{H} + \frac{S}{M} + \frac{S}{L} + \frac{B}{H} + \frac{B}{M} + \frac{B}{L}\right] \quad (02)$$

$$\text{Momentum} = \text{MOM} = \frac{1}{12} X \left[\frac{S}{H} + \frac{S}{M} + \frac{S}{L} + \frac{B}{H} + \frac{B}{M} + \frac{B}{L}\right] \quad (03)$$

$$\text{Illiquidity} = \text{ILLQ} = \frac{1}{24} X \left[\frac{S}{H} + \frac{S}{M} + \frac{S}{L} + \frac{B}{H} + \frac{B}{M} + \frac{B}{L}\right] \quad (04)$$

$$\text{Market Premium} = \text{Mkt} = \text{Rm} - \text{Rf} \quad (05)$$

$$\text{Price Earning Premium} = \text{PEP} = \frac{1}{24} X \left[\frac{S}{H} + \frac{S}{M} + \frac{S}{L} + \frac{B}{H} + \frac{B}{M} + \frac{B}{L}\right] \quad (06)$$

$$\text{Inv} - \text{Sentiment} = \text{ISP} = \frac{1}{24} X \left[\frac{S}{H} + \frac{S}{M} + \frac{S}{L} + \frac{B}{H} + \frac{B}{M} + \frac{B}{L}\right] \quad (07)$$

Similar econometric methodologies have been used in various applications of energy and economics (Baloch et al., 2020; Sun et al., 2020a; Sun et al., 2020b; Sun H et al., 2020) and (Sun et al., 2020a). For size premium, we categorized portfolios into three subcategories in comparison to the median value of the portfolio with market capitalization.

$$\frac{S}{L} = ç \int It < \bar{X}_{It} \quad (08)$$

$$\frac{S}{M} = ç \int It = \bar{X}_{It} \quad (09)$$

$$\frac{S}{H} = ç \int It > \bar{X}_{It} \quad (10)$$

These are three categories of portfolios on the base of a size where ∫ symbolizes o portfolio, ç represents market capitalization, and $\bar{x}$ indicates median of portfolios at *t* time period. Portfolio with a lower market capitalization than median is ranked as "Small", being equal to ç is named as "middle/midpoint", and a portfolio having higher capitalization is named as "Large". On book to market ratio these portfolios are subdivided into three categories:

$$\frac{B}{L} = \int It = 30\%\text{fi} < \dot{\text{B}}\dot{\text{M}} \quad (11)$$

$$\frac{B}{M} = \int It = 40\%\text{fi} = \dot{\text{B}}\dot{\text{M}} \quad (12)$$

$$\frac{B}{M} = \int It = 30\%\text{fi} > \dot{\text{B}}\dot{\text{M}} \quad (13)$$

Afterward, each portfolio is extended to two further categories by adapting market return R_{it} as a fourth pricing factor. Returns of P.S.X are subdivided into "H" indicating high return and "L" as low market return on historical bases. And the portfolio is considered as a winner if peak return is represented by "U". There were 12 portfolios where S is about the small size, B is for Big, H is for a high book to market ratio, M shows mid ratio of book to market, and L represents the lower ratio. So, the index formation of portfolios of market, size, value, and momentum is, $^{\delta}$it is capital pricing model of assets, $^{\delta}$mt is market return, and $^{\delta}$ft is risk-free return of market at *t* sample assessment time of study. Thus, we aim to assess the proportion of momentum, value, market, size, and sentiment premium in pricing models of the Pakistani stock exchange by assessing the following model,

$$\delta_{\text{it}} = \alpha + \varphi_{2\text{it}} + \varphi_{3\text{it}} + \varphi_{4\text{it}} + \varphi_{5\text{it}} + \varphi_{6\text{it}} + \varphi_7{}^*{}_{\text{it}} + \varepsilon_{it} \quad (14)$$

δ is net result as the difference of risky and risk-free return (C.A.P.M) as dependent variable, α is constant φ_2 is size premium factor, φ_3 is value premium, φ_4 Illiquidity premium, φ_5 is price earning factor, and φ_7 is investor sentiment of I portfolios on *t* time. We measured $\varphi_7{}^*{}_{\text{it}}$ (Investor sentiment) by five proxies: market returns, divided premium, equity shares, Herding behavior, and the disposition effect.

$$\varphi_7{}^*{}_{\text{it}} = \omega_1 \text{PSXR}_{\text{it}} + \omega_2 \text{DP}_{\text{it}} + \omega_3 \text{EQS}_{\text{it}} + \omega_4 \text{HB}^*_{\text{it}} + \omega_4 \text{DE}^*_{\text{it}} \quad (15)$$

We measure herd behavior by the model presented by (Chandio et al., 2020) and (Sun H et al., 2020). We operate with a value deviation model to infer true dispersion in findings. We assess value deviation of portfolios returns γ as high returns $\prod^U$ and declining returns $\prod^D$; m is about market returns. Here DE* is measured by another proxy to measure investor

TABLE 2 | Correlation Analysis.

	PF	VP	SP	PEP	MP	MOM	ISP	ILLQ
PF	1	—	—	—	—	—	—	—
VP	0.026	1	—	—	—	—	—	—
SP	0.073	0.047	1	—	—	—	—	—
PEP	0.186	-0.021	−0.238	1	—	—	—	—
MP	0.071	0.013	0.328	−0.103	1	—	—	—
MOM	0.071	0.0137	0.328	−0.103	1.00	1	—	—
ISP	0.003	0.098	−0.002	0.023	−0.005	−0.005	1	—
ILLQ	0.150	0.104	0.043	0.071	−0.095	−0.095	−0.095	1

TABLE 3 | Unit root test.

Variable	R Sq	DW	SE	Prob*
ILLIQ	0.36	2.07	0.09	0.000
MOM	0.66	2.04	0.14	0.000
MP	0.17	2.02	0.05	0.002
PEP	0.36	2.00	0.09	0.000
SP	0.22	2.05	0.09	0.016
VP	0.35	2.00	0.09	0.000
PF	1.04	2.00	0.09	0.000

sentiment that declares investors feeling regret in loss and pride in winning, also known as disposition effect. We use holding periods of investors having particular equity in portfolios Δt is holding period, θ_t are outstanding shares, V_t market volume daily in Rupee, and $n\int$ trading duration of portfolios in days (Iqbal et al., 2021; Zhang et al., 2021). Behavioral finance argues that value deviation of herd behavior in market factors result in herd behavior and pride regret behavior being not only a self-driven attitude of investor defining investor sentiment it also pinches market prices severely to nun-fundamental practice resulting fragility in equity prices. So, we adopted the price fragility model from (Alemzero et al., 2020a; Alemzero et al., 2020b; Sun H et al., 2020), in which G_{it} is equity fragility in prices, θ_{2it} is square of market capitalization, W' is vector of (K x 1) ownership of portfolio equities, Ω_t is metrics of equity funds on variance-covariance bases as (K x K), and K is number of equities in a portfolio (Chien et al., 2021; Iqbal et al., 2021; Li et al., 2021). Moreover, we aimed to evaluate factorial contribution of pricing proponents of equity in price fragility of equity, where G_{it} is dependent, constant as α, and we have seven factors of equity price from $\varphi_{1\ \text{to}}\ \varphi_7$ comprising on value, market, size, momentum, illiquidity, price earning, and investor sentiment premium with ε_{it} error representation (Hsu et al., 2021; Ehsanullah et al., 2021; Zhang et al., 2021).

$$G_{it} = \alpha + \varphi_{1it} + \varphi_{2it} + \varphi_{3it} + \varphi_{4it} + \varphi_{5it} + \varphi_{6it} + \varphi_7{}^*{}_{it} + \varepsilon_{it} \quad (16)$$

The Descriptive Tests, Correlation Tests, Variance inflation factor Test, Serial Correlation at Lags, Unit Root Tests, ARDL Test, and Robustness Test were deployed for analysis of study (Agyekum et al., 2021; Zhang et al., 2021). The results of the study propose the following research model:

$$G_{it} = \alpha + \varphi_1 (\text{VP})_{it} + \varphi_2 (\text{SP})_{it} + \varphi_3 (\text{PEP})_{it} + \varphi_4 (\text{Illiq})_{it} + \varepsilon_{it} \quad (17)$$

The study found four variables impacting price fragility in generally equal mean variant and random trading behavior of Pakistani stock market. The abbreviations of the variables are,

G_{it} = Equity Price Funds Fragility.
VP = Value Premium.
SP = Size Premium.
PEP = Price Earning Premium.
Illiq = Illiquidity Premium.
ε_{it} = error of *i* intersection at *t time period.*

RESULTS AND DISCUSSION

In **Table 1**, the mean value of PF, VP, PEP, and ISP ranges from 0.2 to 2.3 and SP, MP, MOM, and LLIQ ranges from 117 to 943. Median values of PF is 0.004, VP, 0.88, SP 113.2, PEP 2.3, MP 133.3, MOM 233.3, ISP 0.37, and ILLIQ 841.3. The maximum range of the values is from 1.45 to 458 and the minimum range of values is 0.000–44.4. The standard deviation ranges from 0.2 to 48.4 where the maximum deviation is found in Illiquidity.

In **Table 2**, the value premium is negatively correlated with price fragility as 0.026. Size premium is correlated with price fragility as 0.073 and with value premium as 0.047. Price earning premium correlates fragility of prices as 0.186, negatively correlating −0.021 with value premium, −0.238 with size premium. Market premium is 0.071 correlated with price fragility, 0.013 with value premium, and 0.238 with size premium. Momentum premium is correlated with funds fragility of price as 0.071, 0.013 with a premium of fund value, 0.328 with size, and negatively correlated as −0.137 with price earnings premium. Moreover, investor sentiment premium is correlated with fragility 0.003, with value premium as 0.098, −0.002 with size premium, 0.023 with market premium, and −0.05 with momentum premium. Similarly, Illiquidity is correlated 0.15 with fragility, 0.104

TABLE 4 | Auto regressive distributed lag.

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
PF(−1)	−0.18	0.09	−1.9	0.0520
VP(−1)	−7.71	3.7	−2.09	0.0384
SP(−4)	−0.02	0.007	−2.33	0.0214
PEP	1.18	0.66	1.76	0.0800
MOM	−0.004	0.008	−0.48	0.6299
ISP	−0.02	0.05	−0.43	0.6679
ILLQ (−1)	4.58	1.5	3.10	0.0025
R-sq	0.31	MD Var		1.41
Adjusted R-sq	0.20	S.D. Var		7.34
S.E.	6.55	Akaike info criterion		6.72
Log LH	−364.19	Hannan-Quinn Criterion		6.89
Prob (F-statistic)	0.011	DW		1.99

TABLE 5 | Variance inflation factor.

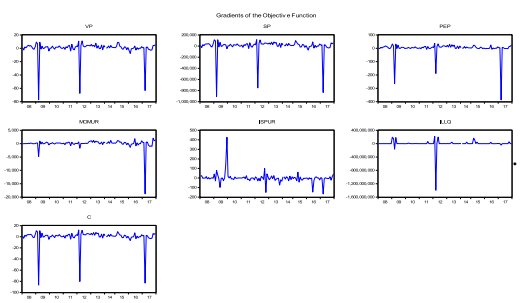
Variable	VIF
VP	1.025888
SP	1.188325
PEP	1.069551
MOM	1.137008
ISP	1.022915
ILLQ	1.046536

with value premium, 0.043 with size premium, 0.071 with price earning premium, and −0.95 with market premium, momentum, and investor sentiment.

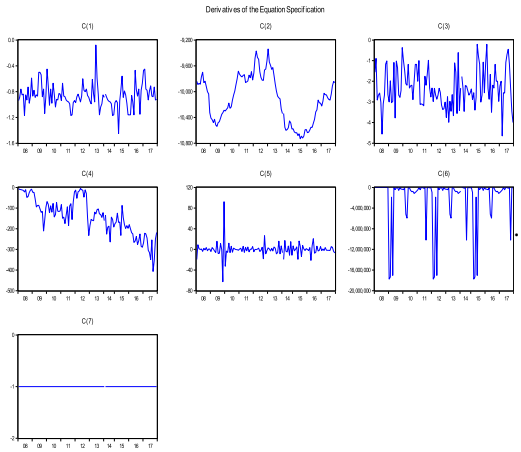
In **Table 3**, we use the Augmented Dicky Fuller—Mackinnon, 1996) test that clarifies the serial correlation via Durbin Watson as 2.07 of Illiquidity, 2.04 of Momentum, 2.02 of market premium, 2.00 of Price Earnings Premium, 2.05 of Size premium, 2.00 of value premium, and 2.00 of price fragility. Moreover, the results reject the null hypothesis of unit root that value premium, size premium, price fragility, price earning, momentum, and illiquidity has no unit root 0.000 ($p < 0.10$). Residual Squares range from 0.17 of momentum to 1.04 of price fragility. And standard error is 0.05–0.14. Hence, the results explained no unit root in the data.

In **Table 4**, the serial correlation in data indicates the use of more specified and sophisticated tools for further data analysis. However, as per unit root in data, ARDL is deployed that resulted in variables of study on level and at first difference. Thus, price fragility, value premium, Illiquidity, and price earning premium are found to be negatively significant at first lag with 0.0520, 0.0384,0.0025, and 0.0800 ($p < 0.10$). Size premium is found to be significant at SP (−4) 0.0214 ($p < 0.10$) with price fragility. Market premium is excluded from analysis due to a singular matrix having its contribution as zero. And momentum of equity funds and sentiments are found to insignificantly affect price fragility as 0.63 & 0.67 ($p > 0.10$). F stats is 0.011 ($p < 0.10$). There is low serial correlation compositely as 1.99, showing that the data is normal with 6.55 standardized errors of estimates and R Square is low at 0.31. Therefore, trends of pricing multi-factors with price fragility are as follows.

Graph 01: Gradient Graph of Pricing Factors and Price Fragility at Level and First Deference ARDL



Graph 2: Coefficient Graph of Variables at First Difference and at Level in ARDL



To further elaborate lags at first difference, at level, and graphics of study variables tested hetroskedasticity tests and found there is no hetroskedasticity with the values in desired criteria. Moreover, variance inflation factor in **Table 5** ranging from 1.03 to 1.18, supporting the results of ARDL test that the data is normal with no serial correlation compositely but exists variable wise individually. Therefore, removing item wise serial correlation pricing factors are found to be significant at lags with price fragility.

To enforce the study findings in ARDL results, Bai-Perron test is deployed by using least square method with breaks of data (**Table 6**). Here R-Square is 0.34 in comparison to R square in **Table 4** as 0.31. Durbin Watson is 2.098 and F Stats is quite parallel as 0.05 with 0.011 in ARDL table results. Thus, the results are robust in size premium, Price earning premium, and Illiquidity, which are positively significant with price fragility at break one. Value premium and constant are negatively significant but momentum and investor sentiments are found to be insignificant with fragility. In the second break, results are non-robust and data is found to be volatile in this break where VP, SP, PEP, MOM, and ISP are insignificant and Illiquidity is significant. Market premium is found on a singular matrix and is excluded from analysis. The findings are novel as resulting pricing factors participation in price fragility is more in the short run and less in the long run. Moreover, there are no fundamental and systematically adaptive trends in the Pakistani stock exchange nor sentimental rituals with equity prices of funds. There is a random walk in the market with general equilibrium behavior.

CONCLUSION AND IMPLICATIONS

The study aims to assess the role of equity fund prices on price fragility by investigating the Pakistan stock exchange from January 2008 to December 2017. This research is segmented into two classifications affecting price fragility: conventional

TABLE 6 | Robustness test.

Variable	Coefficient	Std. error	t-statistic	Prob.
		Break 1: 2008/01—2009/05		
VP	−44.9	17.6	−2.55	0.0122
PEP	4.7	1.84	2.60	0.0107
SP	0.04	0.01	4.03	0.0001
MOM	−0.09	0.08	−1.11	0.2716
ILLQ	1.09	3.34	3.27	0.0014
ISP	−0.36	0.30	−1.18	0.2381
C	−467.7	114.0	−4.10	0.0001
		Break 2: 2009/06—2017/12		
VP	−2.18	3.46	−0.62	0.5306
PEP	0.99	0.74	1.33	0.1860
SP	−0.002	0.001	−0.99	0.3215
MOM	0.002	0.008	0.22	0.8212
ILLQ	3.37	1.56	2.16	0.0327
ISP	0.018	0.045	0.38	0.6980
C	19.4	19.87	0.97	0.3297
R-squared	0.34	Mean dependent var	1.39	
Adjusted R-squared	0.14	S.D. dependent var	7.22	
S.E. of regression	6.68	Akaike info criterion	6.74	
Sum squared resid	4603.26	Schwarz criterion	7.08	
Log likelihood	−380.84	Hannan-Quinn criter.	6.88	
F-statistic	2.48	Durbin-Watson stat	2.098	
Prob (F-statistic)	0.005			

pricing factors and behavioral antecedents. Literature indicated multiple pricing factors of conventional pricing system and behavioral anomalies affecting equity prices by making it fragile. Thus, it is framed to test these pricing factors affecting equity prices fragility in Pakistan. However, this testing procedure is facilitated to test market portfolios by decomposing them into book-to-market ratio and size. So, this research discussed what pricing multifactor to use and what the nature of their effects are on price fragility. Thus, size, value, Illiquidity, market, and momentum premium are suggested by the literature as conventional pricing factors. Price earning premium is another vital conventional factor of pricing included to uncover various unique issues. Moreover, investor sentiment is included as a behavioral factor here composed of herding behavior and disposition role of market players. Various theoretical gaps and empirical issues in PSX motivated us to investigate this model to address price fragility conflict and short-term trading reversal attitude of market investors in PSX.

The results reveal that value, size, and Illiquidity significantly affect price fragility at p value less than 0.10. It explains that a negative change in equity price will be found by a change in size, value, and Illiquidity of equity funded portfolios. The results support the findings of (Fama & McBath, 1973) and hypothesis one, two, and four are accepted. Price earning premium is also found tp be significant on price fragility, revealing that extensive cross trading of short term investors is enhancing fragility in funds prices. Moreover, it guides the trading path to arbitrage investors to follow this short-term trend and contribute to building thinness in equity prices that is far away from fundamental trading behavior, causing msspricing in markets. Hence, it is the actual reason for less score of PSX price multiples in comparison to developed markets. Therefore, hypothesis five is also accepted.

Market premium is excluded during data analysis by its uniform matrix nature and its hypothesis is rejected. The results also suggest that there is insignificant participation of investor's sentiment and momentum in price fragility because investors are working with a short-term approach. And these sentiments are not consistent in the long -run to predict momentum and sentimental behavior in equity portfolios. Moreover, investors are following a short trend and minutely disposing of their trading position, which is difficult to explain on consistent bases on price fragility of equities. Hence, hypothesis seven is also rejected.

Marginal inconsistency failed to predict behavioral aspects effect on the fragility of prices. So, we used Bi person test of robustness with least square approach of breaks in data to capture sensed change in causal response. Thus, results concluded that conventional market factors of pricing are found to be significant on price fragility in the short run but entirely insignificant in the long run. While, there is no momentum and procedural behavior in the sentiments prevailing in PSX in both the short- and long-term time break.

Research Implications

The local exchange market is dynamic in nature and, theoretically, there is a dire need to propose multiple contextual models for equity pricing and to address mispricing

issues in developing exchange markets. These models should cover contextual, conventional, anomalistic behaviors, earning motives, investor type, time-variant, sensitive, volatile, and liquidity-oriented determinants of equity prices. Secondly, SEC Pakistan and PSX should systematically develop a framework for improvement of earnings multiples score because a lower score of PE multiples and price earning affect on price fragility of equities is alarming. Thirdly, the security exchange commission should impose tight limitations and legal bindings on extensive price-earnings by short investors and should motivate capital gain acquisition in investors. Forth, to maximize capital gain focus of short-term investors there is need to amend company laws of governance and there is high need to introduce a corporate democratic culture. Fifth, to capture investor's sentiments a well-versed and dynamic instrument should be launched by PSX because already available sentiments covering ingredients are not covering the scope and global sentiment proxies are not capturing the true picture of local investor behavior.

Study Limitations

The literature is biased toward studying equity pricing factors of portfolios constructed by the stock market of Pakistan instead of studying single equity funds. To study the equity prices of portfolios only includes mean prices/returns of the portfolios due to investment diversification. There is no other way for diversification. Moreover, some studies have found that equity price prediction is less efficient due to portfolios and have recommended to study equ ity wise comparatively. Due to the focus on portfolio prices, firm characteristics are presenting less important information on diversifying the funds and portfolio analysis. For a more in-depth study, the time and data limitation, macroeconomic pricing factors, and rational behavioral factors are not incorporated in the investigation model. The study is limited to the Pakistani context, which imposes a contextual limitation.

The results of the study are clearly indicating that there is inconsistent behavior in the Pakistani stock exchange where price fragility is a less identified issue that has drastic and volatile effects on other financial fundamental behaviors. The results highlighted that conventional factors are affecting price fragility negatively in the short run and there is less momentum and sentimental behavior in it. In the long run, there is no such kind of significant working of conventional and behavioral aspect financial systems. The per unit change in size, illiquidity, and value premium are causing a uniform change in equity funds price structure in the short-term. But market premium, momentum, and sentiments are not affecting it. Moreover, price earning premium has significantly affected price fragility and has approved the hypothesis that there is short-term behavior in the Pakistani exchange market causing multiple issues. Price earning premium is also found to be insignificant in the long run. Hence, the findings of this research are coherent with theoretical bases in the local context.

Future Recommendations

The current study has shown that pricing factors and fragility are more predictable in the short run than long run because Pakistan has an inconsistent economic system influenced by inconsistent political situations. In future research, the political regimes of past ten to fifteen years should be included, and their public financial policies with a recent model could present novel findings. Such analysis of political financial aspects with price fragility can also show that either random walk and mean-variance behavior is an internal flaw of stock market or it is affected by political policies and the fragility of national governments. Another study on price fragility and misricing in Pakistan and across countries can also present unique findings.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MA: Conceptualization, Data analysis ZY: Writing-review SA: Writing-original draft SA: Conceptualization, Data analysis, Writing-original draft MA: Proofreading, Writing review.

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Revealing the Impacts of Banking Sector Development on Renewable Energy Consumption, Green Growth, and Environmental Quality in China: Does Financial Inclusion Matter?

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China aims to reduce its carbon dioxide emissions and promote green growth. This study aims to examine the effect of banking sector performance indicators (banks assets and return on asset) and financial inclusion on renewable energy consumption, green growth, and carbon emissions for China from 1995 to 2020 using the ARDL approach. The long-run results suggest that bank assets increase renewable energy consumption and green growth. While return on assets also increases green growth and decreases carbon emission in the long run. Financial inclusion enhances renewable energy consumption and green growth, curbing CO_2 emissions. Banking sector performance and financial inclusion have short-run effects on renewable energy consumption, green growth, and carbon dixoside emissions. The findings thus point to the need for policies that promote banking sector performance and financial inclusion to boost green growth and alleviate CO_2 emissions.

Keywords: banking sector development, renewable energy consumption, green growth, CO2 emissions, Pakistan

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INTRODUCTION

Indeed, economic growth is crucial for reducing poverty, raising the people's living standards, and developing the necessary infrastructure to provide health and educational facilities to most people. Energy is the key element in the grown of the economy (Ahmad et al., 2019). Economic development, being the potential of an economy, is the most viable factor observed by the world's nations (Khan et al., 2022). Economies grow over time, whereas the initial state of growth usually remains slow (Sun et al., 2020). Economic development is the potential of any economy. Nevertheless, economic development has some social costs attached to it in the form of environmental degradation due to the overutilization of natural resources (Ullah et al., 2021a). Although China has achieved unprecedented economic development in the past few decades, Chinese people have witnessed an enormous increase in living standards. Still, China has become the world's leading carbon emitter (Sun et al., 2020). The banking sector is necessarily required to upgrade and reduce the CO_2 emission as the banking performance affects heterogeneously to the banking performance which categories the measure of renewable energy consumption (Zhang et al., 2021).

To increase the energy efficiency, it is nesserarly to improve the size of the bank, the quality of the asset, and the efficient management of the HI nations (Gyimah et al., 2022). A detailed description of

the term "inclusive development" is hypothetical (Mohsin et al., 2019). As an effect, the idea is correspondently used with associated thoughts such as "inclusive growth." this leads to significant uncertainty in the literature and policy agendas from several organizations, administrations, and the country's government (Pasimeni & Pasimeni, 2016). In each field, the environmental characteristic of any plan and strategy is a vital topic to address. Climate change has brought serious consequences for the Earth's ecological balance, such as rising temperature, melting glaciers, droughts, floods, extreme weather, food insecurity, and deterioration of the worker's efficiency (Solarin et al., 2017; Wei & Ullah, 2022).

Study of Zakarya et al. (2015) investigated the dynamic factors affecting CO_2 emissions in the 12 Middle East countries using panel data from 1990-to 2009. CO_2 used, and trade is used affect the financial up-gradation, and there is a bidirectional relationship both in the short and long run. Therefore, the issue of climate change and its detrimental impact on humanity has got paramount importance in the eyes of empirics, policymakers, and civil society. Due to the significance of the issue of climate change, environmental economists and policymakers have shifted their focus from a traditional growth concept to a more sophisticated, modern, sustainable one. The environmentally friendly notion of growth is green growth (Li et al., 2022). From 1990to 2018, inflation instability is linked to pollution and carbon emissions in 40 countries. An increase in the price variety affects investment projects and consumption (Mohsin et al., 2019). It has resulted in economic growth, increasing the breakdown and causing the environment lower condition. To improve the environment, financial stability is essential (Al Asbahi et al., 2019).

The continuous degradation of the environment due to rising temperature and its harmful impact on human lives has made the goal of sustainable development a top focus of the international community. As a result, the policymakers in many countries have tried to implement various environmental strategies and policies that can address the issue of climate change. The Paris Pact and Sustainable Development Goals (SDGs) can be termed practical steps toward improving the environment (OECD, 2020). According to the OECD, (2020), the SDGs have become a crucial objective for policymakers in developed and developing economies (Ahmad et al., 2019; Mohsin et al., 2019). However, the steps taken by the various countries in this regard are quite different so as their outcomes. For instance, due to various policy measures, Australia and Belgium are enjoying high green growth compared to Portugal and Turkey, facing stagnant green growth (Ahmad et al., 2021).

In this age of increasing globalization and modernization, when the environmental problem is multi-dimensional, cannot deal with this problem with one size fit all strategy; hence, it required to examine different factors that can help decouple economic growth from CO_2 emissions. Study suggested that green growth is a type of growth that can be achieved through efficient and sustainable use of natural resources and capital. Green growth represents the path towards a more green and sustainable economy (Iram et al., 2020). Green growth is a process of utilizing natural resources sustainably (Dercon, 2014). The ultimate goal is to raise people living standards, reduce inequality and poverty, develop infrastructure without exerting an extra burden on the environment, and protect the environment for future generations.

On one side, green economic growth has become the norm of the new environmental strategy adopted by almost every nation (Dercon, 2014; Linster & Yang, 2018). On the other side, traditional economic activities are considered the primary drivers of CO_2 emissions. Therefore, literature is enriching as far as the determinants of environmental quality are concerned. Most studies have confirmed that economic growth adversely affects the environmental quality at the early stages and improves ecological quality (Stern, 2004). Although the literature on the nexus between economic growth and environmental quality is still flourishing, the inclusion of new variables has cleared many questions in the mind of policymakers about this relationship. One such variable is financial development which has become a primary driver of economic growth (Li et al., 2022). However, its impact on environmental quality is underexplored. Development of the financial sector, represented mainly by banking sector development, may influence energy-related emissions positively or negatively.

On the one hand, the development of the banking sector may promote technological innovations in the energy sector and help to reduce emissions. However, the banking sector also fosters industrial and manufacturing activities that increase energy-driven emissions (Amuakwa-Mensah & Näsström, 2022). Moreover, the research and development activities also flourish due to progress in the financial sector which spurs economic activities and consequently impacts environmental quality (Frankel and Romer, 1999). Lie et al. (2021) used data from China from 1970 to 2015 to estimate the linkage between CO_2 emission per capita, energy power, real economic growth (per capita), industrial sectors, urban rate of population, and renewable energy consumption. Analysis of this study (ARDL) was used for both short-run and long-run (VECM) to find causality. Renewable energy and GDP had positive and unidirectional causality relations in the short-run, while other variables had bidirectional causality. In this study, the researcher gave policy suggestions to improve the environment, reduce carbon emissions, and improve energy use and banking efficiency.

Zhang et al. (2019) used panel data from 1996 to 2017 to estimate the carbon dioxide emission in BRICS countries. This study estimated short termed and long termed data was analysied and shows that using variables like; per capita GDP, energy structure (ratio of renewable energy consumption to total energy consumption), and economic structure (value-added service industry to GDP and contribution service industry to economic growth). The CO_2 correlated effect mean group (CCEMG) was used to find the relationship between economic development and carbon emissions. The results according to EKC are inverted U-shape relation in GDP with CO_2 and CCEMG method; reduction in carbon dioxide by an increase in renewable energy consumption. The banking performance affects heterogeneously the banking performance, which categories the measure of renewable energy consumption. To increase

the energy efficiency it is necessarily to increase the size of bank, the quality of asset, efficiency management of the HI nations.

Although banking sector development has become a crucial variable in determining the environmental quality and economic growth (Yang et al., 2020). Financial inclusion has become an integral part of the development of the financial sector (Ullah et al., 2021b). Financial inclusion implies the easy availability of a wide variety of financial products and services to a majority of people (Ullah et al., 2020).

An inclusive and vibrant financial sector provides easy credit facilities for investment in green energy technologies that can significantly improve environmental quality (IPA, 2017). Conversely, an increase in financial inclusiveness helps the economy to achieve scale effect through increased production and manufacturing activities that contribute to environmental degradation. Similarly, an inclusive financial system allows individuals to consume more energy-intensive products, infusing carbon emissions into the atmosphere (Ahmad et al., 2021).

In the light of the above discussion, it is imperative to include the variables of financial development and financial inclusion as determinants of environmental quality, green growth, and renewable energy consumption. This is the first-ever study that has tried to capture the effect of banking sector development and financial inclusion on China's environmental quality, green growth, and renewable energy consumption. Although previous studies have included one or the other variable related to the financial sector, none have observed the collective impact of banking sector development and financial inclusion on the CO_2 emissions, green growth, and renewable energy consumption in the context of China. The choice of China as a country is not by chance but instead based on the fact that China is the largest consumer of energy and the largest emitter of carbon in the world.

Financial Inclusion Review

Financial inclusion development has increased in the early 1990s with development and technological revlolution on policy-making for economically deprived people (Leyshon and Thrift 1995; Sanderson et al., 2018). Financial inclusion is the easy accumulation of capital, security, and a safe way to save, and it is a significant driver of economic growth (Claessens and Perotti 2007). Women will play a larger role in banking if families and companies have simple access. Such actions boost economic growth (Sahay et al., 2015). Financial inclusion can increase economic growth through small business value creation, which improves human capital through improving health and education, which is vital for economic development, as well as reducing inequality and poverty (Agnello et al., 2012). Sarma (2008) created an index based on several characteristics to calculate financial inclusion for a group of countries. Arora (2010) used a similar method for developed and developing economies. The researchers looked at economic growth and financial inclusion from multiple aspects. Sethi & Acharya, (2018) stated dynamic, resilient, and efficient financial sector drives economic growth. If private enterprises have easy access to credit and financial services, business would boost per capita income (Kiplimo et al., 2015).

Mohan (2006) noted that improving the role of financial intermediaries boosts economic growth and financial development. Estrada et al. (2010) found a relationship between poverty and financial access. Donou-Adonsou and Sylwester (2016) found microfinance hurts poverty in emerging countries. The banking sector decreases poverty in the same economies. Research on the effects of financial inclusion on economic growth and other variables is extensive, but research on the environment is in its infancy. Li et al. (2022) collected data from 31 countries between 2004 and 2014 to study the association between financial inclusion and CO_2 emissions.

Renzhi and Baek (2020) found a negative link between financial inclusion and CO_2 emissions. Financial inclusion may improve environmental quality by lowering economic expansion's negative effects. Zhang et al. (2019) examined the impact of financial inclusion on CO_2 emissions in OECD nations from 2004 to 2014 and found that it reduces CO_2 emissions in some economies in the short and long term. Increasing financial inclusion in China lowered CO_2 emissions. Therefore this study attempted to capture the effect of banking sector development and financial inclusion on China's environmental quality, green growth, and renewable energy consumption. Although previous studies have included one or the other variable related to the financial sector, none have observed the collective impact of banking sector development and financial inclusion on the CO_2 emissions, green growth, and renewable energy consumption in the context of China. The choice of China as a country is not by chance but instead based on the fact that China is the largest consumer of energy and the largest emitter of carbon in the world.

Model and Methods

Theoretically, banking sector development works as a channel of green credit and financial services. Renewable energy consumption impacts green growth and environmental quality (Amuakwa-Mensah & Näsström 2022). Empirically, banking sector development has increased green growth and environmental quality by increasing renewable energy consumption (Cao et al., 2021; Amuakwa-Mensah & Näsström, 2022). Following the standard earlier studies (Samour et al., 2019; Zafar et al., 2019; Amuakwa-Mensah & Näsström, 2022), renewable energy consumption, green growth, CO_2 emissions are given as a function of banking sector development and financial inclusion as follows in **Eq. 1**.

$$REC_t = \Upsilon_{10} + \Upsilon_{11}BSP_t + \Upsilon_{12}FI_t + \Upsilon_{13}ICT_t + \Upsilon_{14}FDI_t + \Upsilon_{15}Trade_t + \mu_{1t} \quad (1)$$

$$GG_t = \Upsilon_{20} + \Upsilon_{21}BSP_t + \Upsilon_{22}FI_t + \Upsilon_{23}ICT_t + \Upsilon_{24}FDI_t + \Upsilon_{25}Trade_t + \mu_{2t} \quad (2)$$

$$CO_{2,t} = \Upsilon_{30} + \Upsilon_{31}BSP_t + \Upsilon_{32}FI_t + \Upsilon_{33}ICT_t + \Upsilon_{34}FDI_t + \Upsilon_{35}Trade_t + \mu_{3t} \quad (3)$$

In the above specification **Eqs 1–3**, renewable energy consumption (REC), green growth (GG), and CO_2 emissions (CO_2) are determined by the banking sector performance (BSP),

financial inclusion (FI), information and communication technologies (ICTs), foreign direct investment, inflow (FDI), trade openness (Trade), and random error term ($\boldsymbol{\varepsilon_t}$). Based on the standard literature, we expect an estimate of $\boldsymbol{\Upsilon}_{11}$ and $\boldsymbol{\Upsilon}_{21}$ to be positive if the banking sector may enable customers and firms to provide low rate funds for renewable energy consumption and green technologies. While we expect the estimate of banking sector development elasticity's to be negative in CO_2 emissions. The analysis is not limited to the long-run estimates only; hence, the above long-run equation is respecified in the form of an error correction format given below:

$$\begin{aligned}\Delta REC_t = {} & \Upsilon_{10} + \sum_{k=1}^{n}\beta_{11k}\Delta REC_{t-k} + \sum_{k=0}^{n}\beta_{12k}\Delta BSP_{t-k} \\ & + \sum_{k=1}^{n}\beta_{13k}\Delta FI_{t-k} + \sum_{k=0}^{n}\beta_{14k}\Delta ICT_{t-k} \\ & + \sum_{k=1}^{n}\beta_{15k}\Delta FDI_{t-k} + \sum_{k=1}^{n}\beta_{16k}\Delta Trade_{t-k} \\ & + \Upsilon_{11}REC_{t-1} + \Upsilon_{12}BSP_{t-1} + \Upsilon_{13}FI_{t-1} + \Upsilon_{14}ICT_{t-1} \\ & + \Upsilon_{15}FDI_{t-1} + \Upsilon_{16}Trade_{t-1} + \lambda.ECM_{t-1} + \mu_{1t}\end{aligned} \tag{4}$$

$$\begin{aligned}\Delta GG_t = {} & \Upsilon_{20} + \sum_{k=1}^{n}\beta_{21k}\Delta GG_{t-k} + \sum_{k=0}^{n}\beta_{22k}\Delta BSP_{t-k} \\ & + \sum_{k=1}^{n}\beta_{23k}\Delta FI_{t-k} + \sum_{k=0}^{n}\beta_{24k}\Delta ICT_{t-k} \\ & + \sum_{k=1}^{n}\beta_{25k}\Delta FDI_{t-k} + \sum_{k=1}^{n}\beta_{26k}\Delta Trade_{t-k} \\ & + \Upsilon_{21}GG_{t-1} + \Upsilon_{22}BSP_{t-1} + \Upsilon_{23}FI_{t-1} + \Upsilon_{24}ICT_{t-1} \\ & + \Upsilon_{25}FDI_{t-1} + \Upsilon_{26}Trade_{t-1} + \lambda.ECM_{t-1} + \mu_{2t}\end{aligned} \tag{5}$$

$$\begin{aligned}\Delta CO_{2,t} = {} & \Upsilon_{30} + \sum_{k=1}^{n}\beta_{31k}\Delta CO_{2,t-k} + \sum_{k=0}^{n}\beta_{32k}\Delta BSP_{t-k} \\ & + \sum_{k=1}^{n}\beta_{33k}\Delta FI_{t-k} + \sum_{k=0}^{n}\beta_{34k}\Delta ICT_{t-k} \\ & + \sum_{k=1}^{n}\beta_{35k}\Delta FDI_{t-k} + \sum_{k=1}^{n}\beta_{36k}\Delta Trade_{t-k} \\ & + \Upsilon_{31}CO_{2,t-1} + \Upsilon_{32}BSP_{t-1} + \Upsilon_{33}FI_{t-1} + \Upsilon_{34}ICT_{t-1} \\ & + \Upsilon_{35}FDI_{t-1} + \Upsilon_{36}Trade_{t-1} + \lambda.ECM_{t-1} + \mu_{3t}\end{aligned} \tag{6}$$

Equations 4–6 can simultaneously produce short and long-run estimates, known as the ARDL model of Pesaran et al. (2001). Multiple advantages characterize the PMG/ARDL approach. One of the main advantages of ARDL is that the estimation is possible even when the explanatory variable is endogenous. Furthermore, as long as the ARDL model is free of the residual correlation, endogeneity is a minor problem.

In recent years, the Johnson test was used in the short term and long term relationship among variables for the empirical analysis (Spann, 1974). Still, these tests are problem-creating and have some disadvantages. After a few times, in 1998, Pearson and shin introduced the model to find long-run and short-run results. The Autoregressive Distributed Lag Model (ARDL) is moderately used as an econometrician approach (Shahbaz et al., 2020; Zheng et al., 2021). If the explanatory variables refer to one or more lagged values of the dependent variable, it is identified as an autoregressive or dynamic model. If any structural break exists in the series, the Auto-Regressive Distributed Lag model gives us information. The ARDL bound test can automatically resolve the serial correlation of residuals (Pesaran & Shin, 1995). Another advantage of using the ARDL model is that it is unnecessary to specify whether variables have integrated order one or a zero. Hence, there is no need to check the stationarity of variables. ARDL can be used to check the long-run association between variables regardless of the level of stationarity. However, according to Shehbaz et al. (2011) if variables have integrated order two I(2), then the value of the F-statistic will not remain valid because of violation of the assumption that the integrated order of variables should be zero or one, it is necessary to ensure that no variable is stationary at integrated order two I(2).

Pesaran et al. (1999) the suitable lags in the ARDL model may be used to account for both residual correlation and endogeneity. ARDL has an advantage over single equation cointegration analysis such as having the problem of endogeneity, but ARDL can tell which variables are dependent and which are explanatory, which is very important. To estimate the long-run parameters that are linearly normal, the ARDL technique is utilized, regardless of whether the variables are in the range of zero to one **Eq. 1**. Furthermore, it calculates the long-run and short-run outcomes and the error correction for each parameter (Zhu & Peng, 2012).

It is possible to get the short-run estimates from the first-differenced variables by solving **Eqs 4–6**. According to Pesaran et al. (2001), the limits F-test is used to determine whether or not long-run variables are cointegrated. In contrast to all other time series approaches such as Johansen (1988) has used the ARDL model may perform effectively even if specific variables are stationary at the level and other variables are fixed at the first difference. Another feature of the ARDL approach is that it performs well even when a small sample size is used (Bahmani-Oskooee et al., 2020; Usman et al., 2021). It incorporates a short-run dynamic process, it is a better approach in terms of its ability to cope with endogeneity and serial correlation, among other things (Pesaran et al., 2001). Finally, diagnostic tests such as the Lagrange Multiplier (LM) and the Breusch-Pagan (BP) tests have been used to discover autocorrelation and heteroscedasticity issues in the data. Ramsey's RESET command is used to correct model misspecification. We use the cumulative sum (CUSUM) and the cumulative sum-square (CUSUM-square) to assess the stability of short- and long-run characteristics.

Data (1995–2020)

The study intends to investigate the impact of banking sector expansion on renewable energy consumption, green growth, and environmental quality in China from 1995 to 2020.

Table 1 presents descriptive data, definitions, and variable symbols. There are three dependent variables in the research; three models regress it. These dependent variables include renewable energy consumption (total energy consumption in quad Btu), green growth (environmentally adjusted multifactor productivity), and CO_2 emissions (in kilotons). Three characteristics are used to measure the development of the banking sector: bank assets, return on assets, and ATMs. Bank

TABLE 1 | Definitions and descriptive statistics.

Variables	Definitions	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
REC	Total energy consumption from nuclear, renewables, and other (quad Btu)	1.614	1.604	2.797	0.523	0.798	0.006	1.519
Green growth (GG)	Environmentally adjusted multifactor productivity	8.864	8.615	13.134	7.103	1.298	1.825	6.620
CO_2	CO_2 emissions (kilotons)	15.64	15.77	16.26	14.93	0.476	-0.355	1.525
BA	Deposit money banks assets to GDP (%)	124.9	120.3	174.5	82.39	23.64	0.485	2.606
ROA	Bank return on assets (%, after tax)	0.940	0.978	1.545	0.431	0.332	0.110	2.307
ATMS	ATMs per 100,000 adults	30.26	13.70	91.36	1.808	31.78	0.922	2.266
ICT	ICT index	32.80	30.39	73.56	1.304	23.97	0.150	1.611
FDI	Foreign direct investment, net inflows (% of GDP)	3.297	3.500	4.725	1.311	1.077	-0.507	2.146
TRADE	Trade (% GDP)	45.28	43.82	64.47	32.42	10.12	0.539	2.026

TABLE 2 | Unit root tests.

	DF-GLS			ADF		
	I(0)	I(1)	Decision	I(0)	I(1)	Decision
REC	−2.875***		I(0)	−2.785*		I(0)
GG	−2.785***		I(0)	−2.658*		I(0)
CO_2	−0.287	−2.987***	I(1)	−0.589	−3.898***	I(1)
BA	−0.485	−3.289***	I(1)	−1.785	−3.248**	I(1)
ROA	−1.855*		I(0)	−2.654*		I(0)
ATMS	−0.145	−2.754***	I(1)	2.012	−2.756*	I(1)
ICT	−0.423	−1.986**	I(1)	0.325	−3.658**	I(1)
FDI	−0.415	−5.365***	I(1)	−0.921	−5.965***	I(1)
TRADE	−1.452	−3.248***	I(1)	−1.564	−3.556**	I(1)

*Note: ***p < 0.01; **p < 0.05; *p < 0.1.*

assets are calculated as a percentage of GDP, returns on assets are calculated after-tax, and ATM data is calculated per 100,000 individuals. The ICT index, foreign direct investment, and trade role are included as control variables. The IMF, OECD, and World Bank provided the data for the study.

RESULTS AND DISCUSSION

The unit root features of the data were checked before undertaking regression analysis in this research. According to the finndings the DF-GLS and ADF unit root tests were used to complete this work. The coefficient estimates for both unit root tests are shown in **Table 2**. DF-GLS and ADF coefficient estimates show that renewable energy consumption, green growth, and asset returns are level stationary variables. In contrast, according to the tests, CO_2 emissions, bank assets, ATMs, information and communications technology, foreign direct investment (FDI), and trade are the first difference static variables. As a result of these results, the ARDL technique was used for the regression analysis in the research. **Table 3** summarizes the models' conclusions for renewable energy consumption, energy growth, and CO_2 emissions throughout the long and short-term timeframes.

The long-run results of the renewable energy consumption model show that bank assets report a statistically significant and positive rise in renewable energy consumption over the long run. A one percent increase in bank assets results in a 0.011 percent rise in renewable energy usage over the long term. ATMs have been shown to have a significant and considerable impact on the use of renewable energy over the long term. It has been discovered that a one percent increase in the number of ATMs has the potential to increase renewable energy usage by 0.003 percent. Results indicated that there is a favorable relationship between the expansion of the financial industry and the use of renewable energy. Amuakwa-Mensah and Näsström (2022) provide evidence to support this good relationship. According to the literature, there are two avenues *via* which the expansion of the banking industry might impact the use of renewable energy.

Firstly, the expansion of the financial sector encourages the use of renewable energy sources by encouraging technological innovation and the accumulation of wealth. Second, allocating financing to lucrative projects helps increase the use of renewable energy by encouraging more people to do so. These results imply that a well-organized banking sector can minimize liquidity risk and increase financial resources for green investments in renewable energy resources, as shown by the findings. For example, the banking industry in China, Germany, and Sweden has launched green auto loans and mortgages based on the usage of environmentally friendly cars and renewable energy sources. Aside from that, large-scale investments are necessary for advancing technological innovation and the development of renewable energy resources, which might be made feasible by the availability of financial assistance (Zheng et al., 2021). In the long term, information and communications technology (ICT) and trade factors contribute to positive and significant growth in renewable energy consumption. However, foreign direct investment (FDI) has a negligible impact on renewable energy use in the long term. The short-run findings of the renewable energy consumption model show that bank assets and ATMs tend to increase renewable energy consumption in the near term. ICT, trade, and foreign direct investment (FDI) all indicate a beneficial impact on renewable energy use in the near term.

Concerning the green growth model, the data over the long term suggest that bank assets and ATMs significantly promote

TABLE 3 | Short and long-run estimates of renewable energy consumption, green growth, and CO_2 emissions.

Variable	REC		GG		CO_2	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short-run						
BA	0.009***	2.279	0.157**	2.029	0.006***	2.852
BA(−1)	0.024***	6.046	−0.284***	2.648	−0.018***	3.305
BA(−2)	−0.009***	2.731			0.004	1.535
ATMS	0.007	1.644	0.071	0.839	−0.007*	1.894
ATMS(−1)	0.014***	3.063	0.082	0.931	−0.008**	2.298
ATMS(−2)			0.312***	2.894	0.011***	2.904
ICT	0.057***	5.688	1.194***	2.684	−0.027***	3.375
ICT(−1)			−2.326***	3.009	−0.087***	2.911
ICT(−2)			1.095***	2.593	0.071**	2.485
FDI	0.099**	2.013	0.079	0.117	−0.035	1.096
FDI(−1)	0.092*	1.817			−0.101***	2.632
FDI(−2)	−0.087*	1.723			−0.060***	2.722
TRADE	0.029***	4.100	0.012	0.123	0.011***	3.357
TRADE(−1)	0.007	1.037	0.225**	2.156	0.002	0.811
TRADE(−2)	0.031***	4.080	0.100	1.625	−0.010***	2.679
Long-run						
BA	0.011***	3.565	0.046**	2.203	−0.002	1.267
ATMS	0.003*	1.679	0.057***	2.882	−0.001	0.798
ICT	0.027***	22.65	0.013	0.497	−0.021***	10.83
FDI	0.050	1.200	0.028	0.117	0.063***	2.662
TRADE	0.004**	2.322	0.114***	8.084	0.011***	6.100
C	1.040**	2.472	8.266***	3.033	1.035***	6.540

*Note: ***p < 0.01; **p < 0.05; *p < 0.1.*

green growth. A one percent increase in the number of bank branches and ATMs increases green growth by 0.046 and 0.057 percent, respectively, according to the data collected by the researchers. A good link is observed between banking sector development and green growth in our research, and this relationship is reported in the studies done by (Aslam et al., 2021; Cao et al., 2021). According to research issued by the Asian Expansion Bank (2012), cited Abe (2013) the development of the banking sector is essential to produce new technologies and industrial goods that take environmental quality, green growth, and energy efficiency into mind. Two routes are involved in developing the banking sector's contribution to green development.

The expansion of the banking sector may help lessen the impact of environmental fluctuations and damages on human society and the economic system. Second, the development of the banking sector facilitates access to financial resources and contributes to promoting green growth. The literature has stated that low-cost loans are essential to achieve the objectives of greenhouse gas emission reduction. In the case of control variables, the results indicate that information and communications technology (ICT) and foreign direct investment (FDI) have a negligible connection with green growth. Still, trade is strongly and positively connected with green growth in the long term. The short-run results of the green growth model suggest that bank assets have a statistically significant and positive relationship with green growth. Still, ATMs have a statistically insignificant relationship with green growth. The control variables suggest that information and communications technology (ICT) is strongly and positively

TABLE 4 | Short and long-run estimates of renewable energy consumption, green growth, and CO_2 emissions.

Variable	REC		GG		CO_2	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short-run						
Diagnostics						
F-test	12.55***		5.987***		8.655***	
ECM(-1)*	−0.406***	12.59	−0.462***	8.785	−0.470***	9.049
LM	0.542		0.785		2.012	
BP	0.654		0.452		1.021	
RRESET	1.254		1.325		0.365	
CUSUM	S		S		S	
CUSUM-sq	S		S		S	

*Note: ***p < 0.01; **p < 0.05; *p < 0.1.*

TABLE 5 | Short and long-run estimates of renewable energy consumption, green growth, and CO_2 emissions (Robustness).

Variable	REC		GG		CO_2	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Short-run						
ROA	0.073	0.382	2.869***	3.181	0.161**	2.261
ROA(-1)			1.594	1.239	0.053	1.245
ROA(-2)			4.662***	2.666	0.133***	2.739
ATMS	0.014	1.095	0.011	0.086	0.012	0.029
ATMS(-1)	0.018	1.645	0.338***	2.770	0.010**	2.169
ATMS(-2)	0.011	1.362	0.174	1.587	0.010***	2.581
ICT	0.039	1.592	1.038**	2.469	0.016*	1.664
ICT(-1)	0.126***	3.019	0.949**	2.536	0.013	0.923
ICT(-2)	0.165***	3.569	0.440	1.066	0.027	1.355
FDI	0.069	0.956	0.669	1.030	0.002	0.074
FDI(−1)	0.117*	1.910	0.845	1.346	−0.017	0.834
FDI(−2)	0.128	1.407	0.790	1.434	−0.050**	2.425
TRADE	0.010	1.449	0.052*	0.738	0.007***	3.086
TRADE(−1)	0.001	0.143	0.194**	1.960	0.004	1.389
TRADE(−2)	0.016	1.544	0.188**	2.266	−0.004	1.018
Long-run						
ROA	0.044	0.370	1.008***	4.252	−0.233***	3.488
ATMS	0.013**	2.564	0.052**	2.243	−0.005***	3.400
ICT	0.047***	7.565	0.118***	3.596	−0.021**	2.396
FDI	0.188***	2.710	0.207	0.610	0.060	1.355
TRADE	0.005*	1.781	0.111***	8.124	0.011***	8.036
C	1.284***	4.232	2.252**	2.480	4.587***	6.383
Diagnostics						
F-test	4.325*		3.987*		6.354***	
ECM(−1)*	−0.670***	7.416	−0.571***	8.187	−0.470***	17.82
LM	1.988		1.365		1.355	
BP	0.365		1.355		0.325	
RESET	1.587		0.254′		1.302	
CUSUM	S		S		S	
CUSUM-sq	S		S		S	

*Note: ***p < 0.01; **p < 0.05; *p < 0.1.*

connected with green growth. Still, that trade and foreign direct investment (FDI) reports have no meaningful influence on green development in the near term.

In the CO_2 emissions model, the long-term data indicate that bank branches and ATMs have a negligible impact on CO_2 emissions in the long run. ICT has both substantial and adverse effects on CO_2 emissions, with evidence indicating that increased usage of ICT leads to a reduction in CO_2 emissions and, consequently, an improvement in environmental quality. Thus, higher energy consumption reduces ecological quality by increasing carbon emissions due to the expansion of the industrial setup. The growth of the banking industry has resulted in an increase in CO_2 emissions, which has been increasing. In contrast, after reaching a certain level of development, the banking sector may see a surge in energy innovations, resulting in cleaner energy from other sources (Shahbaz et al., 2013; Smulders et al., 2014). The amount of CO_2 emissions might begin to decline. The studies conducted by Shahbaz et al. (2013) and Zafar et al. (2019) both found a similar association between the two variables.

In contrast, foreign direct investment (FDI) and international commerce (trade) have a significant and beneficial influence on CO_2 emissions in the long term, suggesting that growth in FDI and international trade increases CO_2 emissions, hence deteriorating environmental quality. Bank branches have considerable and growing impacts on CO_2 emissions in the near term, but ATMs have significant and decreasing effects on CO_2 emissions in the short term. In the near term, information and communications technology (ICT) results in a significant reduction in CO_2 emissions. In the short term, trade, on the other hand, has the effect of increasing CO_2 emissions. The relationship between FDI and CO_2 emissions is statistically negligible in the short run.

The diagnostic testing results demonstrated in **Table 4** indicated that the coefficient estimates derived from ARDL models are accurate and reliable. LM and BP tests revealed no evidence of heteroskedasticity or autocorrelation, which was verified by the outcomes of the study. According to the Ramsey RESET test results, all of the models have been appropriately defined. The CUSUM and CUSUM-sq tests demonstrate that all of the models are stable. It is possible to have long-run cointegration among variables, as shown by the coefficient estimates of the ECM test and the F-statistics.

The coefficient estimates of robustness models for the long-run and short-run are shown in **Table 5**. The renewable energy consumption model results demonstrate that returns on assets

have a negligible impact on renewable energy consumption in the long term. In contrast, automated teller machines (ATMs) positively impact renewable energy consumption. The return on assets and ATMs both state that the effect on renewable energy usage is modest in the near term. Long-term, the green growth model findings demonstrate that the return on assets and the use of ATMs contribute to a significant and positive increase in green growth, respectively. Increasing return on investments has improved green growth in the short run; however, ATMs have had a minor influence on green development in the near term. The results of the CO_2 model demonstrate that return on assets and automated teller machines (ATMs) have the potential to cut CO_2 emissions over the long term considerably. However, return on investments has a considerable and favorable influence on CO_2 emissions in a short time, but the return on equity does not (Mohsin et al., 2019). The results of control variables in robust models are consistent with the findings of fundamental models in both the short- and long-run.

DISCUSSION

The study examines the impact of financial inclusion on environmental quality and economic performance from 1995 to 2019. Financial inclusion is measured by ATM, ICT, FDI and premiums. Empirical research uses panels. The study's variables show long-run paneln. Long-term, bank branches positively affect economic efficiency, implying that as bank branches expand, economic performance rises. Long-term bank loan increases economic growth and pollution. The influence of insurance premiums on economic growth is statistically insignificant, indicating no long-term correlation. Insurance premiums have a significant adverse impact on carbon emissions, confirming that rate increases reduce emissions over time.

Long-term energy use favorably affects economic growth and pollutant emissions (Ullah and Ozturk, 2020). Long-term, trade's influence on CO_2 emission is mainly negative in the insurance rate regression model. Long-term bank branch regression is the only economic-environmental consequence of population growth. Short-term, banking institutions increase carbon dioxide emissions, therefore more branches means more emissions. Short-term bank lending doesn't affect the economic performance (Mohan, 2006). In the near run, higher insurance premiums reduce economic growth and carbon emissions. The findings reveal policy recommendations. Financial inclusion fosters economic growth, according to our research. Our study suggests that long-term economic development requires financial sector changes. To reduce the effects of economic inequality by extending access to financial services, it is important to understand the relationship between financial inclusion, economic growth, and poverty.

Authorities and policymakers in these economies should adopt and implement digital financial inclusion. Financial inclusion should support Asia's growing markets. Through financial inclusion, financial institutions may support green energy initiatives (Iram et al., 2020).

The monies should be allocated to green firms, enterprises, and individuals. The government should also set strong criteria for financial institutions to lend for renewable energy and environmentally-friendly initiatives. Digital financial inclusion can help with this. Governments should reduce digital financial inclusion hurdles including cost, paperwork, and trust. Policymakers should expand climate finance to help economically disadvantaged groups cope with rising CO_2 emissions. Individual and SMB climate finance can help reduce CO_2 emissions. Sohail et al. (2021) agree that green investment in public and commercial sectors, through the financial sector, is vital if the economy wishes to transform from a high emission to low carbon green economy.

CONCLUSION AND IMPLICATIONS

The growth of the financial sector, particularly the development of the banking sector, has played a critical role in the economic success of a country. Over the last several years, financial inclusion has emerged as a vital component of any modern monetary system. Financial inclusion refers to the availability and accessibility of economic goods and services to as wide a range of individuals as feasible. A financially inclusive system may aid in promoting environmentally friendly productive activities in the economy. Still, it can also help in decoupling economic growth from environmental damage. Increased inclusion in banking sector development offers cash for investment in clean and green technology and renewable energy projects, which contribute to the promotion of both green growth and environmental quality at the same time (De Gregorio and Guidotti, 1995). Our primary goal in this research is to determine the influence of the expansion of the banking sector and financial inclusion on renewable energy consumption, green growth, and the quality of the environment.

Checking if the variables are stable at the level or initial difference is step one in doing an empirical study of a data set. ADF and DF-GLS are two unit root tests used to demonstrate that our variables combine I(0) and I(1). Therefore, the ARDL model is the most suitable model to use to get estimates of the variables. Banking sector growth and financial inclusion are represented by three separate variables: assets held by banks, return on assets earned by banks, and the number of ATMs available. The findings of the baseline ARDL model imply that bank assets have a beneficial effect on green growth and renewable energy consumption in the long term while having a negative but minor impact on CO_2 emissions. These results suggest that the improvement in the banking sector leads to an increase in renewable energy consumption and green growth over the long term.

Similarly, the increase in financial inclusion leads to a rise in renewable energy use and green growth while having no discernible influence on CO_2 emissions. In the robust model, we have utilized return on assets rather than bank assets to measure risk. Only in the robust green growth model the long-run estimates of return on the investment are positively significant. Still, they are negatively substantial in the CO_2

emissions model alone. On the other hand, ATMs have a favorable impact on the estimates of renewable energy consumption and green growth while having a negative impact on the estimates of CO_2. The F-test and the ECMt-1 tests are also used to validate the robustness of the long-run findings obtained. On the other hand, the short-term outcomes are equivocal and inconsistent. The findings are significant in the development of specific policies. According to one point of view, the banking sector is critical for decoupling economic growth from CO_2 emissions and increasing renewable energy consumption; as a result, policymakers should strengthen its position in every area of the economy, especially in the energy and environmental sectors. As a second point, the policies of growth of the financial industry must be coordinated with those of the environment and energy. Third, authorities should emphasize the importance of inclusion in the financial sector. This will give finances and credit for investment in green production activities and renewable energy projects, which will benefit all of society. Last but not least, governments should make an effort to employ information resources rather than physical resources since this would aid in decoupling economic growth from CO_2 emissions and making economies more weightless. This study has not analyzed digital financial inclusion, however, three indicators of financial inclusion based on usage and access to formal financial services since relevant data for Asian developing economies was unavailable. Future research should employ various digital financial inclusion proxies. Future research can cover updated models and data. Future academics may evaluate the high-pollution economy at the micro - level.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

This idea was given by MK. MK and RR analyzed the data and wrote the complete paper. While RR read and approved the final version.

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Carbon Trading or Carbon Tax? A Computable General Equilibrium–Based Study of Carbon Emission Reduction Policy in China

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To solve the environmental problems caused by climate change, the Paris Agreement urges China to accelerate the pace of CO_2 emission reduction. Carbon trading and carbon tax have been considered the key instruments in reducing CO_2 emissions. The focus of this article is not only to examine the impact of carbon trading and the carbon tax policy on China's macroeconomy but also to study the "carbon trading–carbon tax" mixed policy and make a comparative analysis based on the computable general equilibrium (CGE) model. We found that the mixed policy is more favorable to China's macroeconomy than a single carbon emission reduction policy and is conducive to improving people's welfare. If a carbon tax is carried out, a relatively mild and low carbon tax rate should be adopted to achieve China's carbon emission reduction goal and have a favorable impact on the macroeconomy. The main purpose of this article is to provide a theoretical basis and policy advices for the Chinese government in formulating innovative carbon reduction policies.

Keywords: CGE model, carbon trading policy, carbon tax policy, mixed policy, carbon reduction policies

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1 INTRODUCTION

As the world's largest emitter of greenhouse gases, China accounts for about 30% of the world's total carbon emissions. Carbon emission reduction is a major environmental problem facing China (Jiang et al., 2018). As early as 2011, China launched a pilot program of carbon emission trading in seven cities and provinces, including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen. After nearly a decade of exploration, as of November 2020, carbon markets in the pilot provinces and cities have covered more than 20 industries, including steel, power, and cement, with nearly 3,000 enterprises. The cumulative trading volume quota is about 430 million tons of carbon dioxide, and the cumulative trading volume is nearly 10 billion yuan. On 16 July 2021, the national carbon emission trading market was officially launched, covering more than 4.5 billion tons of carbon emissions annually, making it the largest carbon market covering greenhouse gas emissions in the world. Carbon emission trading and carbon tax are the two main carbon emission reduction tools based on the market mechanism, which is a classic research proposition of environmental economics to argue over their merits (Zhang et al., 2022).

A large number of studies have proved that compared with traditional policy instruments based on administrative orders, economic incentives such as emission trading schemes and carbon taxes have absolute advantages in saving transaction costs, promoting emission reduction technology innovation, and stimulating the enthusiasm of participants (Bi et al., 2019; Tran et al., 2019;

Alkaabneh et al., 2021). These methods have become the primary means of controlling carbon emissions in developed countries, including Britain, France, Germany, Australia, and Sweden. Their experience shows that carbon trading and carbon taxes play an essential role in reducing carbon emissions (Carl and Fedor, 2016; Jiang et al., 2018).

However, the emission reduction cost and incentive effect of emissions trading systems and carbon taxes vary obviously in reality. Carbon trading has a better emission reduction incentive effect than carbon tax (Wang et al., 2021; Wu and Yang, 2021), although both can reduce emissions by updating production equipment to improve production efficiency (Zhou et al., 2019), but the imposition of carbon tax will squeeze the profit space of enterprises. Carbon emission enterprises are likely to pass on the extra cost brought by carbon tax to the consumers or downstream producers of the industrial chain by raising the price of their products (Bai and Chen, 2016), which ultimately leads to the deterioration of the overall economy, such as decreased GDP and consumption and increased investment (Tang et al., 2015; Liu et al., 2017).

Carbon tax is a tax-based pricing mechanism that is easier to implement than emission trading (Corradini et al., 2018; Shi et al., 2019). Alkaabneh argued that a carbon tax improves the quality of the environment and offsets the other taxes paid by enterprises (Alkaabneh et al., 2021). This view has been verified. Bohringer and Müller (2014)found that using a carbon tax to offset other enterprise taxes would expand the overall economy and short-run employment. More than that, carbon tax can be used for inclusive green growth by recycling carbon tax revenue for investment to households to improve the distribution of income (Vijay et al., 2020).

The computable general equilibrium (CGE) model has been widely used as an effective tool for analyzing policy effects. The CGE model originated from the general equilibrium theory of Walras. Its most prominent characteristic is that the economic system is regarded as a whole, which can reflect the input–output relationship between the whole social–economic activities and all factors (Carrera et al., 2015). These models are mainly used to assess the positive effects of carbon tax or carbon trading on reducing carbon emissions and the negative impacts on the macroeconomy and social welfare (Liu et al., 2017; Tang et al., 2019). Some scholars also used the CGE model to explore the impact of carbon tax on China's environment and economy (Liu and Lu, 2015). For example, Guo et al. used the CGE model and found that a carbon tax policy would significantly reduce the consumption of fossil fuels and have a negative impact on economic growth. Shi et al. (2019) developed a dynamic computable general equilibrium model to explore the possible impacts of different carbon tax conditions on the energy consumption of the construction sector and the macroeconomy of China. Some other scholars used the CGE model to study the pricing of carbon emission right and the transaction cost of carbon emission reduction in carbon trading mechanisms. For example, Jiang H. D. et al. (2022a), Jiang H. D. et al. (2022b) incorporated the co-benefits of carbon abatement policies into the carbon marginal abatement cost curves and evaluated the total abatement costs and cost-saving effects for China to achieve their nationally determined contributions target. Liu et al. (2019) studied the subsidy and penalty mechanisms in the carbon emission trading market based on a CGE model. Zhou et al. (2018) used the CGE model to analyze the rebound effect. Tang et al. (2019) explored the impact of carbon trading policies on carbon emission reduction costs based on a dynamic CGE model and proposed to adopt a penalty price higher than the carbon price to guarantee the effectiveness of carbon trading policies. In a similar study, Weng et al. (2018) examined the impact of carbon intensity targets on the macroeconomy and welfare of China. Bi et al. (2019) believed that China's carbon trading emission reduction's double dividend and GDP growth will appear through the establishment of a dynamic CGE model.

To sum up, most of the existing literature studies focus on a single carbon emission reduction policy, and there are few comparative studies. Faced with the limitations of the existing literature and based on China's actual national conditions and emission reduction commitments, the question on which policy is better is being raised. So far, there is no clear answer (Liu et al., 2019; Zhu et al., 2019). Therefore, based on the CGE model, this article not only examines the impact of carbon trading and the carbon tax policy on China's macroeconomy but also studies the "carbon trading–carbon tax" mixed policy and makes a comparative analysis to provide references for the Chinese government's carbon emission reduction innovation incentives. This article sets different scenarios in the context of reaching the carbon emission peak as early as 2030 and comes to the conclusion that a hybrid policy can better help reach a carbon emission peak before 2030.

2 METHODOLOGY AND DATA

The "1-2-3" model used in this article is a simplified CGE model initiated by Devarajan, which refers to an open economy with one country, two producing sectors, and three products (Devarajan et al., 1998). The two products that the country produces are as follows: an export good E, which is sold to foreigners and is not demanded domestically, and a domestic good D, which is only sold domestically. The third good is an import M, which is not produced domestically. The model has three actors: one representative resident, one government, and the rest of the world.

2.1 Assumptions of The Computable General Equilibrium Model

The CGE model constructed in this article satisfies three assumptions: 1) the country satisfies the "small country hypothesis", that is, the country is only the receiver of the world market price; 2) the products involved in the "1-2-3" model meet the "product difference hypothesis", and the constant elasticity of substitution (CES) function is used to describe this incomplete substitution relationship between D and M in terms of the demand for goods; constant elasticity of transformation (CET) is used to describe the incomplete substitution relationship between E and D in terms of the

supply of goods. 3) The nominal exchange rate R is taken as the price benchmark for the model and is set as 1.

2.2 Equations of the Computable General Equilibrium Model

The "1-2-3" model consists of four types of equations: real logistics equations, nominal flow equations, price equations, and equilibrium equations.

1) Real flow equations: The real flow equations describe the demand and supply of domestic and foreign products. The total output of domestic products can be used for domestic sales and exports. So the function is specified as a constant elasticity of transformation (CET) function with transformation elasticity $\Omega = 1/(\rho - 1)$, ρ is a substitution parameter, and $\rho > 1$, which is expressed as follows:

$$\bar{X} = A_t\left[\delta_t E^{\rho} + (1-\delta_t)D_s^{\rho}\right]^{1/\rho}, \tag{1}$$

where $\bar{X}$ defines the aggregate output and exogenous given, $\bar{X}$ is the fixed meaning that all primary factor inputs, such as labor and capital, are fully utilized. A_t and δ_t are the efficiency parameter and share parameter, respectively; E is the quantity of the exported product; and D_s is the supply of the domestic products.

Since the producer wants to achieve the goal of maximizing profits, it must satisfy the first-order condition of **(Eq. 1)**:

$$\frac{E}{D_s} = \left(\frac{(1-\delta_t)P^e}{\delta_t P^d}\right)^{\Omega}. \tag{2}$$

Eq. 2 defines the proportional relationship between domestic and export goods as a function of their relative prices, where P^e is the domestic price of the export good; P^d is the domestic price of the domestically produced goods.

We used the Armington assumption, assuming imports and domestic goods are imperfect substitutes. So the function is specified as a constant elasticity of substitution (CES) function with substitution elasticity $\sigma = 1/(1+\varphi)$, and φ is a substitute parameter, which is expressed as follows:

$$Q^s = A_q\left[\delta_q M^{-\varphi} + \left(1-\delta_q\right)D_d^{-\varphi}\right]^{-1/\varphi}, \tag{3}$$

where Q^s is the supply quantity of the composite goods; M is the quantity of the import goods; D_d is the consumption of the domestic goods; A_q is the efficiency parameter; and δ_q is the share parameter.

Given the price of domestic and import goods and the supply quantity of composite goods, consumers must meet the first-order conditions of **(Eq. 3)** to maximize utility:

$$\frac{M}{D_d} = \left(\frac{\delta_q P^d}{\left(1-\delta_q\right)P^m}\right)^{\sigma}, \tag{4}$$

$$Q^D = C + \bar{G} + Z, \tag{5}$$

where P^m represents the domestic price of import goods.Here, Q^D is the total domestic demand; C is the household aggregate consumption; $\bar{G}$ is the government consumption, that is, the government's public purchase; and Z is the total investment.

2) Nominal flow equations: The nominal flow equations describe the relationship between various economic variables measured in monetary terms.

$$\mathrm{T} = t^{m*}R*pw^{m*}M + t^{s*}P^{q*}Q^d + t^{y*}Y + t^{e*}P^{e*}E, \tag{6}$$

where T represents the total income of the government; pw^m is the world price of import goods; P^q is the price of composite goods; t^m is the import tariff rate; t^e is the export tariff rate; t^s is the indirect tax rate; and t^y is the direct tax rate.

$$\mathrm{Y} = P^{x*}\bar{X} - t^{s*}P^{d*}D_s + tr + re^*R, \tag{7}$$

where Y represents the total income of resident; P^x is the price of the total domestic output; tr is the transfer from the government to the private sector; re is foreign transfers to the private sector; and R is the nominal rate.

$$\mathrm{S} = \bar{s}^*Y + R^*\bar{B} + S^g, \tag{8}$$

where S is aggregate savings; $\bar{s}$ is the average savings rate; $\bar{B}$ is the balance of trade; and S^g is the savings of the government.

$$C^*P^t = \left(1-\bar{s}-t^Y\right)^*Y, \tag{9}$$

where P^t is the sales price of the composite goods.

3) Price equations: The price equations describe the price relationship between various economic indicators as follows:

$$P^m = (1+t^m)R^*pw^m, \tag{10}$$

$$P^e = (1+t^e)R^*pw^e, \tag{11}$$

$$P^t = (1+t^s)P^q, \tag{12}$$

$$P^x = \left(P^{e*}E + P^{d*}D_s\right)/\bar{X}, \tag{13}$$

$$P^q = \left(P^{m*}M + P^{d*}D_d\right)/Q^s, \tag{14}$$

where pw^e is the world price of export goods, and **Eqs 10**, **11** define the price of import/export goods as their international market price plus import tariff rate/export tariff rate. **Eq. 12** gives the selling price of composite products in the domestic market. **Eq. 13** defines the price of the total domestic output. **Eq. 14** gives the price of domestic composite products.

4) Equilibrium equations: The equilibrium equations reflect the "general equilibrium" characteristics of the CGE model and describe the state of the market clearing, that is, the equilibrium of each economic account is achieved. The equations are as follows:

$$D_d - D_s = 0, \tag{15}$$

$$Q_d - Q_s = 0, \tag{16}$$

$$pw^{m*}M - pw^{e*}E - ft - re = \bar{B}, \tag{17}$$

$$P^{t*}\mathrm{Z} - \mathrm{S} = 0, \tag{18}$$

$$\mathrm{T} - P^{q*}\bar{G} - tr^*P^q + ft^*R - S^g = 0. \tag{19}$$

TABLE 1 | Variables and parameters in the "1-2-3" model.

Endogenous variable	Exogenous variable
E: export goods	pw^e: world price of import goods
M: import goods	pw^m: world price of export goods
D_s: supply of domestic goods	t^m: import tariff rate
D_d: demand of domestic goods	t^e: export tariff rate
Q^s: supply of composite goods	t^s: indirect tax rate
Q^D: demand of composite goods	t^y: direct tax rate
P^e: domestic price of export goods	tr: government transfers
P^m: domestic price of import goods	ft: foreign transfers to government
P^d: producer price of domestic goods	re: foreign transfers to private sector
P^x: price of aggregate output	$\bar{s}$: average savings rate
P^q: price of composite goods	$\bar{X}$: aggregate output
P^t: sales price of composite goods	$\bar{G}$: real government demand
T: tax revenue	$\bar{B}$: balance of trade
S^g: government savings	R: nominal rate
Y: total income	
C: aggregate consumption	Parameters
S: aggregate savings	A_t, A_q: efficiency parameters
Z: aggregate investment	δ_t, δ_q: share parameters
	ρ, φ: substitution parameters
	Ω, σ: elasticity parameters

Eq. 15 defines the balance between the supply and demand of domestic products in the domestic market. **Eq. 16** defines the balance between the domestic aggregate supply and demand. **Eq. 17** defines the balance of international payments. **Eq. 18** describes the investment–savings equilibrium. **Eq. 19** shows the balance of revenue and the expenditure of the government.

2.3 Parameters and Variables in the Computable General Equilibrium Model

According to the specific situation of the research questions in this article, the variables and parameters in the model are 18 endogenous variables, 14 exogenous variables, and 8 parameters, as shown in **Table 1**.

2.4 Closure of the Computable General Equilibrium Model

The purpose of constructing the CGE model is to find the equilibrium solution. In order to ensure the uniqueness of the equilibrium solution, we need a rule to "close" the model. The total number of endogenous variables in the CGE model should be equal to the total number of equations. At present, there are four macroscopic closure rules for CGE models: neoclassical closure (Kang et al., 2018; Liu, 2018), Kaynes closure, Johansen closure, and Kaldorian closure. The CGE model constructed in this article has 18 endogenous variables, but there are 19 equations. We used neoclassical closure rules to close this model. The characteristic of this closure rule is to delete the independent investment function, that is, **Eq. 18** is eliminated to complete the closure of the model (Liu and Baghban, 2017).

2.5 Data and Calibration of the Computable General Equilibrium Model

2.5.1 Data on the Computable General Equilibrium Model

According to China's current national economic accounting system, the input–output (IO) table is compiled by the National Bureau of Statistics every 5 years and is officially released after 2–3 years. Therefore, this article uses the latest available data—the 2018 input–output table, 2018 China Statistical Yearbook, and 2018 China Financial Yearbook as the data source of the model; the initial data units are 100 million yuan as shown in **Table 2**. During the calibration process, the base period's total output is set to 1.00, and all original data are scaled based on the total output.

2.5.2 Calibration of Exogenous Variables and Parameters of the Computable General Equilibrium Model

The different types of parameters in this model can be divided into two categories: one is the share parameter and the efficiency parameter, which can be obtained by using the calibration method; the second is the elastic parameters, which refers to a large number of existing relevant literature studies and sets the two elastic parameters as 0.6. **Figure 1** and **Figure 2** are, respectively, the calibration of each parameter and variable of the model. The calibration of variables and parameters is directly related to the data so that the automation of the calibration can be completed automatically.

3 SCENARIO SETTING

3.1 Single "Carbon Tax" Policy Scenario

In order to assess the impact of the carbon tax policy on China's economy, we should first measure the embodied carbon emissions in China's GDP. According to relevant data released by the National Bureau of Statistics and the World Bank, China's total carbon emission in 2018 was 10.33 billion tons, and the total GDP in the same year was 689.52 billion yuan ($108.59 billion). Therefore, China's embodied carbon emission per 10,000 yuan ($157.5) of the GDP was about 1.49 tons.

According to the suggestion of China's Ministry of Environmental Protection and the Ministry of Finance, the simulation of a carbon tax is set as 10 yuan/ton ($1.58/ton), 30 yuan/ton ($4.73/ton), and 50 yuan/ton ($7.88/ton). In this situation, China's GDP per 10,000 yuan ($157.5) will generate a 0.149–0.749% additional tax burden. Since the tax burden generated by the carbon tax can be passed on to consumers by increasing the selling price of products, it is regarded as an indirect tax (30). We introduced the carbon tax policy into the CGE model through the exogenous variable "indirect tax rate", that is, every ten thousand yuan of the GDP in China will increase the indirect tax rate by 0.149–0.749%.

This article will use the comparative analysis method to analyze the simulation results, so four scenarios are set: 1) the baseline situation (no carbon tax); 2) low carbon tax rate at 10

TABLE 2 | Dataset of the "1-2-3" model.

Data - China, 2018

	Hundred million (yuan)	Output = 1		Hundred million (yuan)	Output = 1
1. National accounts			3. Fiscal account		
Output (value added)	680,254.12	1.00	Revenue	152,269.23	0.22
Wages	354,109.99	0.52	Non-tax	27,347.03	0.04
			Current expenditure	175,877.77	0.26
GDP at market prices	689,052.00	1.01	Goods and services	132,513.82	0.19
Private consumption	265,980.48	0.39	Interest payments	12,375.65	0.02
Public consumption	97,053.42	0.14	Transfers and subsidies	30,971.87	0.05
Investment	304,439.10	0.45	Capital expenditure	51,176.46	0.08
Exports	148,448.34	0.22	Fiscal balance	−81630.49	−0.12
Imports	125,153.10	0.18			
2. Tax revenue			4. Balance of payments		
Sales and excise Tax	88,433.05	0.13	Exports–imports	23,295.24	0.03
Import tariffs	3,976.24	0.01	Net profits, dividends	−29840.26	−0.04
Export duties	138.20	0.00	Net interest payments	−4,571.65	−0.01
Payroll tax	0.00	0.00	Net private transfers	−180.63	0.00
Personal income tax	8,617.27	0.01	Net official transfers	−361.25	0.00
Capital income tax	29,423.71	0.04	Current account balance	−11658.54	−0.02
Total	108,041.15	0.19			
			External debt	91,962.00	0.14
			Debt service payments	15,282.25	0.02

	A	B
4	**Parameters**	
5		
6	Elasticity for CET (st)	0.6
7	Elasticity for CES/Q (sq)	0.6
8		
9	Scale for CET (at)	=X0/(bt*E0^(rt)+(1-bt)*Ds0^(rt))^(1/rt)
10	Share for CET (bt)	=1/(1+(Pd0/Pe0)*(E0/Ds0)^(rt-1))
11	Rho for CET (rt)	=1/st + 1
12		
13	Scale for CES/Q (aq)	=Qs0/(bq*M0^(-rq)+(1-bq)*Dd0^(-rq))^(-1/rq)
14	Share for CES/Q (bq)	=((Pm0/Pd0)*(M0/Dd0)^(1+rq))/(1+ (Pm0/Pd0)*(M0/Dd0)^(1+rq))
15	Rho for CES/Q (rq)	= 1/sq -1
16		

FIGURE 1 | Parameter calibration of the "1-2-3" model.

yuan/ton ($1.58/ton); 3) medium carbon tax rate at 30 yuan/ton ($4.73/ton); 4) and high carbon tax rate at 50 yuan/ton ($7.88/ton). Through calculations, in the base year without carbon tax, China's indirect tax rate is 13.4770%, after the introduction of the carbon tax, in the low, medium, and high tax rates, China's indirect tax rates are as follows: 13.626, 13.926, and 14.226%.

3.2 Single "Carbon Trading" Policy Scenario

This article uses the carbon quota price of the primary market for carbon trading in the seven carbon trading pilot markets established in China as a reference (see **Table 3**) to set the price of the primary market for carbon trading in the model. Assuming that the national carbon trading price is unified, and according to the average price of the carbon trading pilot market which is between 10–60 yuan ($1.57–9.45) per ton, the following four scenarios are set: 1) the benchmark situation (0 yuan/ton); 2) low carbon price: 20 yuan/ton ($3.15/ton); 3) medium carbon price: 40 yuan/ton ($6.30/ton); and 4) high carbon price: 60 yuan/ton ($9.45/ton).

On 30 June, 2015, the Chinese government announced to the world China's carbon emission reduction commitments, namely, CO_2 emissions per unit of GDP in China should be reduced by 60–65% compared to 2005. China's GDP in 2005 was 184,937.37 billion yuan ($29,127.64 billion), and CO2 emissions were 5.49 billion tons, so China's carbon emission intensity in 2005 was 2.97×10^{-4} t/yuan. According to the data on China Statistical Yearbook 2018, China's GDP in 2017 was 82,712.17 billion yuan ($13,027.17 billion). Assuming an average growth rate of China's

C	D	E	F	G
Exogenous Variables	Base Year	Current	**Endogenous Variables**	Base Year
World Price of Imports (wm)	=Pm0/Er0/(1+tm0)	=wm0	Export Good (E)	=P14
World Price of Exports (we)	=Pe0*(1+te0)/Er0	=we0	Import Good (M)	=P15 + P19
			Supply of Domestic Good (Ds)	=1-E0
Import Tariffs (tm) 1/	=O19/O15	=tm0	Demand of Domestic Good (Dd)	=Ds0
Export Duties (te)	=O20/O14	=te0	Supply of Composite Good (Qs)	=M0 + Dd0
Indirect Taxes (ts)	=P18/Qs0	=ts0	Demand of Composite Good (Qd)	=Qs0
Direct Taxes (ty)	=SUM(P21,P23)/Y0	=ty0		
			Tax Revenue (TAX)	= tm0*wm0*M0*Er0+te0*Pe0*E0+ts0*Pq0*Qd0 + ty0*Y0
Savings rate (sy)	=(Y0 - Cn0*Pq0*(1+ts0) - ty*Y0)/Y0	=sy0	Total Income (Y)	= Px0*X0 + tr0*Pq0 + re0*Er0
Govt. Consumption (G)	=P12/(1+ts0)/Pq0	=G0	Aggregate Savings (S)	=sy0*Y0 + Er0*B0 + Sg0
Govt. Transfers (tr)	=(T11+T12-T8)/Pq0	=tr0	Consumption (Cn)	=P11/Pt0
Foreign Grants (ft)	=T22/Er0	=ft0		
Net Priv Remittances (re)	=SUM(T19:T21)/Er0	=re0	Import Price (Pm)	1
Foreign Saving (B)	=(wm0*M0 - we0*E0 -ft0 - re0)/Er0	=B0	Export Price (Pe)	1
Output (X)	1	=X0	Sales Price (Pt)	=Pq0*(1+ts0)
			Price of Supply (Pq)	1
			Price of Output (Px)	1
			Price of Dom. Good (Pd)	1
			Exchange Rate (Er)	1
			Investment (Z)	=P13/Pt0
			Government Savings (Sg)	= Tax0 - G0*Pt0 - tr0*Pq0 + ft0*Er0
			Walras Law (Z-S)	=Z0*Pt0- S0

FIGURE 2 | Variable calibration of the "1-2-3" model.

TABLE 3 | Average price of carbon trading in the primary market from 2013.06 to 2019.03.

Carbon exchange market	Carbon quota trading price
Shenzhen carbon emission exchange	46.83 yuan/ton ($7.38/ton)
Beijing environmental exchange	52.14 yuan/ton ($8.21/ton)
Shanghai environmental exchange	26.46 yuan/ton ($4.17/ton)
Hubei carbon emission exchange	21.78 yuan/ton ($3.43/ton)
Guangzhou carbon emission exchange	23.75 yuan/ton ($3.74/ton)
Tianjin carbon emission exchange	16.76 yuan/ton ($2.64/ton)
Chongqing carbon emission exchange	13.72 yuan/ton ($2.16/ton)

The exchange rate $ 1 = 6.3465 yuan.

GDP is 7%, it is estimated that China's GDP will reach 1,993,165.13 billion yuan ($313,923.51 billion) in 2030. Based on China's relatively strict emission reduction commitment, which is to reduce by 65% in 2030, China's allowed carbon emission intensity in 2030 should be 20.709 billion tons.

Since China has not yet established a national unified carbon trading market in the base year, it is assumed that the trading price of the carbon allowance in the base year is 0 yuan/ton, and only the primary market is considered. When the carbon price in the primary market is low: 20 yuan/ton ($3.15/ton); medium: 40 yuan/ton ($6.30/ton); and high: 60 yuan/ton ($9.45/ton), the income obtained from the carbon cap-and-trade is 414.18 billion yuan ($65.23 billion), 828.36 billion yuan ($130.47 billion), and 1,242.54 billion yuan ($195.70 billion), respectively. We introduced the carbon trading policy into the CGE model through the exogenous variable "government transfer", thereby evaluating the effects on the endogenous variables in the model.

3.3 Mixed Policy Scenario

In order to examine the influence of the "carbon trading–carbon tax" policy on China's macroeconomic policy and take into consideration that China has established a carbon market but not carbon tax, we set 10 kinds of scenario: 1) the baseline situation (no carbon trading, no carbon tax); 2) when carbon price is low: 20 yuan/ton ($3.15/ton), three scenarios of low carbon tax rate: 10 yuan/ton ($1.58/ton), medium carbon tax rate: 30 yuan/ton ($4.73/ton), and high carbon tax rate: 50 yuan/ton ($7.88/ton) are considered, respectively; 3) when the carbon price is medium: 40 yuan/ton (6.30/ton), the three scenarios of a low carbon tax rate: 10 yuan/ton ($1.58/ton), medium carbon tax rate: 30 yuan/ton ($4.73/ton), and high carbon tax rate: 50 yuan/ton ($7.88/ton) are considered, respectively; 4) when the carbon price is high: 60 yuan/ton ($9.45/ton), the three scenarios of low carbon tax rate: 10 yuan/ton ($1.58/ton), medium carbon tax rate: 30 yuan/ton ($4.73/ton,) and high carbon tax rate: 50 yuan/ton ($7.88/ton) are considered, respectively.

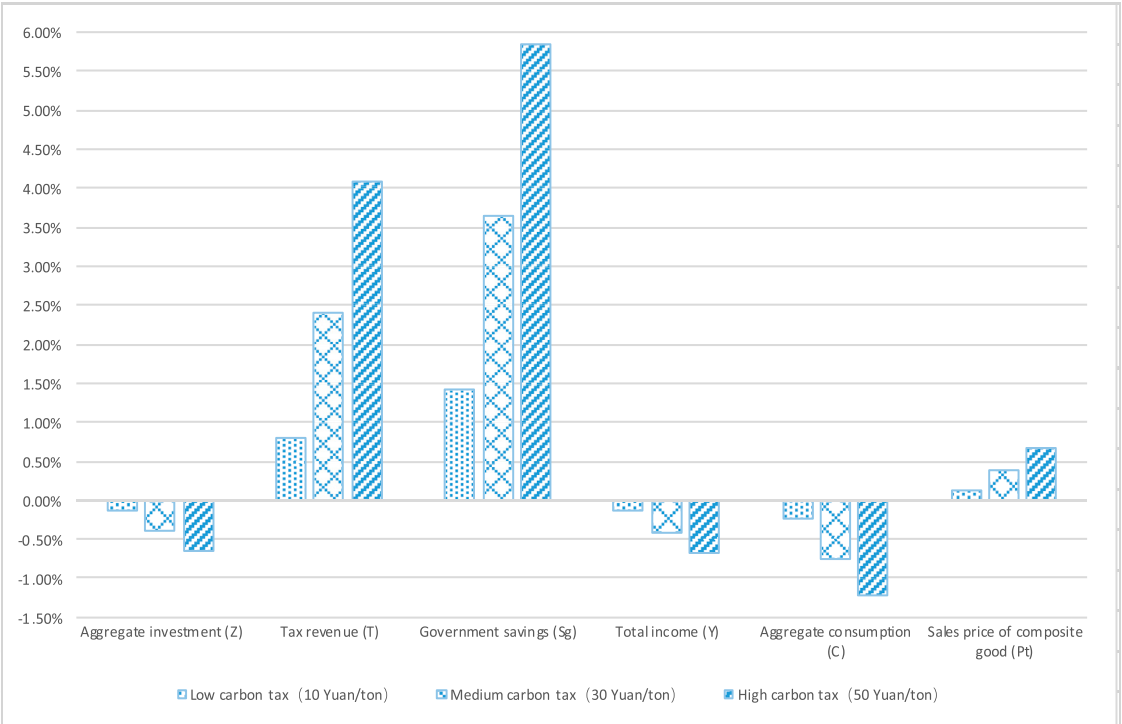
4 RESULTS AND SUGGSTIONS

4.1 Single "Carbon Tax" Policy Simulation Results

The solution of the CGE model in this article is solved by using the "programming solution" in Excel 2010. Since the model is a general equilibrium model, we solved the model under the condition of satisfying the "maximum consumption of the residents" so as to simulate the impact of a carbon tax policy on China's macroeconomy, the data obtained from the simulation (**Table 4**) and the changes in the main macroeconomic variables (**Figure 3**):

TABLE 4 | Simulation results in the carbon tax policy scenario.

Carbon tax scenario / Variable	Baseline (No carbon tax) 0 yuan/ton ($0/ton)	Low carbon tax 10 yuan/ton ($1.58/ton)	Medium carbon tax 30 yuan/ton ($4.73/ton)	High carbon tax 50 yuan/ton ($7.88/ton)
Z	0.3942	0.3937	0.3926	0.3916
T	0.1783	0.1797	0.1826	0.1856
S^g	0.0984	0.0998	0.1019	0.1042
Y	0.8636	0.8624	0.8601	0.8577
C	0.3444	0.3436	0.3417	0.3402
P^t	1.1354	1.1369	1.1399	1.1429



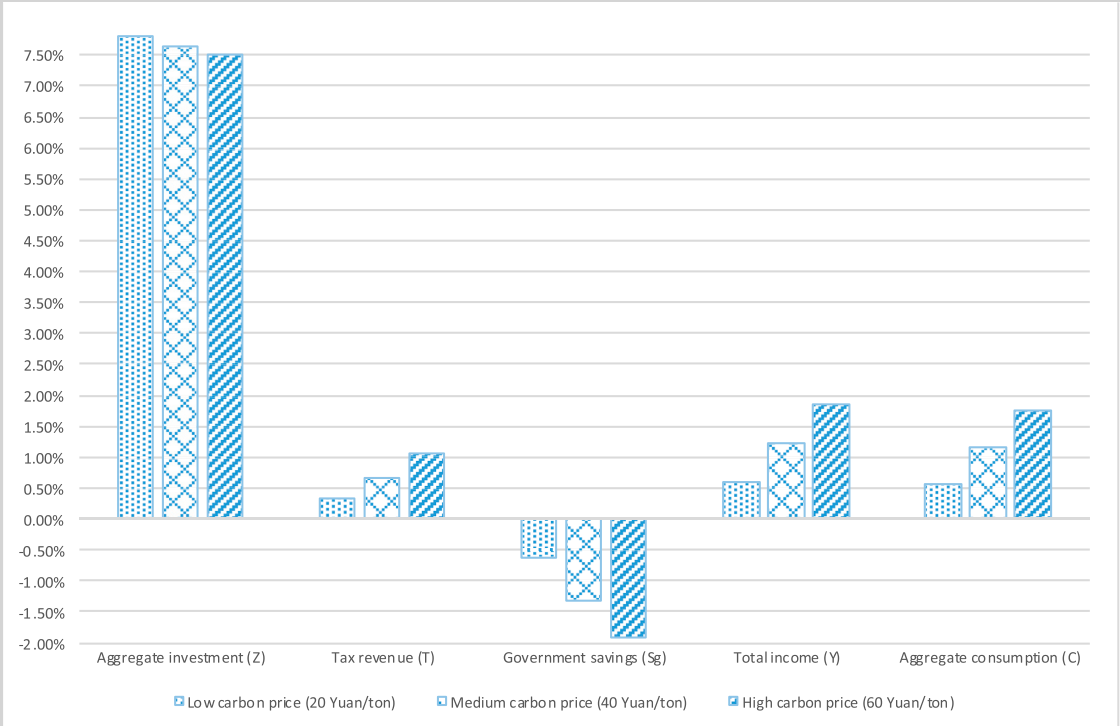
	Low carbon tax（10 Yuan/ton）	Medium carbon tax（30 Yuan/ton）	High carbon tax（50 Yuan/ton）
Aggregate investment (Z)	-0.13%	-0.40%	-0.65%
Tax revenue (T)	0.79%	2.41%	4.09%
Government savings (S^g)	1.42%	3.64%	5.85%
Total income (Y)	-0.14%	-0.41%	-0.68%
Aggregate consumption (C)	-0.23%	-0.76%	-1.21%
Sales price of composite good (P^t)	0.13%	0.39%	0.66%

FIGURE 3 | Impact on macroeconomic variables in the carbon tax policy scenario.

The simulation results show that the implementation of a carbon tax has a certain degree of restraining effect on certain aspects of China's macroeconomy. Among them, total investment, the resident's total income, and consumption all decline, and the degree of decline increases with the continuous increase in the carbon tax rate. The total investment declines as the carbon tax increases. In summary, using carbon tax as a carbon emission reduction tool will lead to

TABLE 5 | Simulation results in the carbon trading policy scenario.

Carbon trading scenario / Variable	Baseline carbon price (0 yuan/ton) ($0/ton)	Low carbon price 20 yuan/ton ($3.15/ton)	Medium carbon price 40 yuan/ton ($6.30/ton)	High carbon price 60 yuan/ton ($9.45/ton)
Z	0.3942	0.4249	0.4243	0.4238
T	0.1783	0.1789	0.1795	0.1802
S^g	0.0984	0.0978	0.0971	0.0965
Y	0.8636	0.8688	0.8742	0.8796
C	0.3444	0.3464	0.3484	0.3504
P^t	1.1354	1.1354	1.1354	1.1354



	Low carbon price (20 Yuan/ton)	Medium carbon price (40 Yuan/ton	High carbon price (60 Yuan/ton)
Aggregate investment (Z)	7.81%	7.65%	7.51%
Tax revenue (T)	0.33%	0.67%	1.06%
Government savings (S^g)	-0.61%	-1.32%	-1.93%
Total income (Y)	0.61%	1.23%	1.85%
Aggregate consumption (C)	0.58%	1.16%	1.74%

FIGURE 4 | Impact on macroeconomic variables in a carbon trading policy scenario.

the increase in government revenue and savings; the increase in domestic sales prices of goods; and the decrease in total investment, total income, and total consumption with the increase in the carbon tax. Therefore, the carbon tax policy has a profound impact on China's macroeconomic development.

It is noteworthy here that the impact brought by the carbon tax policy to China's macroeconomic system has become more significant with the continuous increase in the carbon tax rate. Therefore, if the government wants to levy a carbon tax, it is particularly important to set a carbon tax rate suitable for China's current economic development. It is recommended to adopt a lower carbon tax rate when the carbon tax starts, carefully assessing its impact on China's carbon reduction and its impact on the macroeconomy. We suggest that the

TABLE 6 | Simulation results of the "carbon trading—carbon tax" mixed policy (based on carbon trading).

Policy mix scenario	Base line	Low carbon price 20 yuan/ton ($3.15/ton)			Medium carbon price 40 yuan/ton ($6.30/ton)			High carbon price 60 yuan/ton ($9.45/ton)		
Variable		Low carbon tax	Medium carbon tax	High carbon tax	Low carbon tax	Medium carbon tax	High carbon tax	Low carbon tax	Medium carbon tax	High carbon tax
Z	0.3942	0.4243	0.4233	0.4224	0.4238	0.4228	0.4218	0.4232	0.4223	0.4211
change rate of Z	-	7.65%	7.40%	7.15%	7.53%	7.26%	7.01%	7.37%	7.11%	6.82%
T	0.1783	0.1798	0.1827	0.1857	0.1802	0.1832	0.1862	0.1807	0.1836	0030.1866
change rate of T	-	0.83%	2.48%	4.16%	1.08%	2.73%	4.41%	1.34%	2.99%	4.67%
S^g	0.0984	0.0992	0.1014	0.1036	0.0985	0.1007	0.1029	0.0979	0.1001	0.1022
change rate of S^g	-	0.86%	3.08%	5.29%	0.15%	2.37%	4.58%	-0.53%	1.69%	3.89%
Y	0.8636	0.8678	0.8657	0.8636	0.8736	0.8715	0.8693	0.8791	0.8768	0.8748
change rate of Y	-	0.49%	0.24%	0%	1.16%	0.91%	0.67%	1.79%	1.54%	1.30%
C	0.3444	0.3456	0.3449	0.3421	0.3476	0.3459	0.3441	0.3497	0.3480	0.3462
change rate of C	-	0.36%	0.15%	−0.67%	0.94%	0.43%	−0.09%	1.55%	1.04%	0.52%
P^t	1.1354	1.1369	1.1399	1.1429	1.1369	1.1399	1.1429	1.1369	1.1369	1.1429
change rate of P^t	-	0.13%	0.39%	0.66%	0.13%	0.39%	0.66%	0.13%	0.39%	0.66%

government can compensate the consumers using the increased tax, and the rest can be used to encourage the development of new energies.

4.2 Single "Carbon Trading" Policy Simulation Results

The "programming solution" method was used to simulate the impact of the carbon emission trading policy on China's main macroeconomy and the data obtained from the simulation (shown in **Table 5**.) and the changes in the main macroeconomic variables (**Figure 4**).

It can be seen from the simulation results that when the government adopts a carbon trading policy, the investment will increase significantly, the income of the government and residents will increase, the consumption of residents will increase, and the government savings will decrease. It is worth noting that compared with the carbon tax policy, the carbon trading policy can significantly improve the total investment, residents' total income, and total consumption.

4.3 "Carbon Trading—Carbon Tax" Mixed Policy Simulation Results

The influence of the mixed policy of "carbon trading—carbon tax" on China's macroeconomy is obtained by simulation, and the changes of main macroeconomic variables are shown in **Table 6**.

The results of the simulation in **Table 6** show that: 1) the government introduces a carbon tax in the case carbon emission trading being launched; when the carbon price is low: 20 yuan/ton ($3.15/ton) and medium: 40 yuan/ton (6.30/ton), and the carbon tax is low: 10 yuan/ton ($1.58/ton) and medium: 30 yuan/ton ($4.73/ton), the increase in total investment was the most significant. When the carbon price is low: 20 yuan/ton ($3.15/ton), and carbon tax is low: 10 yuan/ton ($1.58/ton) and medium: 30 yuan/ton ($4.73/ton), the investment increases by 7.65 and 7.40% compared with the base year. This shows that a lower carbon tax rate would be more effective in promoting investment; 2) the total income of the government, regardless of the level of carbon price, increases most significantly when the carbon tax is high. When the carbon price is low: 20 yuan/ton ($3.15/ton), medium: 40 yuan/ton ($6.30/ton), and high: 60 yuan/ton ($9.45/ton), the revenue of the government will increase by 4.16%, 4.41, and 4.67% compared with the base year, which suggests that an increase in carbon tax could greatly boost government revenues; 3) regardless of the carbon price, the total income of the residents increases the most when the carbon tax is low: 10 yuan/ton ($1.58/ton), which increases by 0.49, 1.16, and 1.79%, respectively, compared with the base year. The increase gradually reduces as the carbon tax increases, which shows that a lower carbon tax will help increase the total income of residents.

Based on the aforementioned conclusions, we put forward the policy suggestions as follows: 1) compared with the single policy, the mixed policy is more beneficial to China's macro economy; 2) the separate imposition of carbon tax will lead to a decrease in the income of government departments, a decrease in the total income and consumption of household departments, and a rise in the domestic price of consumer goods. Therefore, it is prudent to adopt a single carbon tax; 3) according to the current situation of emission control in China, carbon trading should be implemented independently for a steady period of time before introducing the carbon tax. Furthermore, it should be noted that the carbon tax rate should not be set too high, which will help achieve a "win–win" situation for the environment and economy.

5 CONCLUSION

The focus of our work not only examines the impact of carbon trading and carbon tax policy on China's macroeconomy but also studies the "carbon trading–carbon tax" mixed policy and makes a comparative analysis based on the CGE model, providing policy advices for the Chinese government's carbon emission reduction

innovation incentive. This article draws the following conclusions: First, compared with the implementation of a single carbon tax policy, a mixed policy is more advantageous to the macroeconomy, which not only improves the government income significantly but also greatly improves the negative impact of carbon tax on the total income and consumption of residents to a large extent, which is conducive to improving the living standards and well-being of the Chinese people. Second, compared with the implementation of a single carbon trading policy, the mixed policy will significantly increase the income of the government, and government savings will also increase, but what particularly caught our attention is, a high carbon tax will have a large negative impact on domestic prices, total income, and consumption of residents. Therefore, a relatively moderate and low carbon tax, that is, 10–30 yuan ($1.58–4.73) per ton, should be adopted to achieve China's carbon emission reduction targets and to have a favorable impact on China's macroeconomy. This article sets three different scenarios in the context of reaching the carbon emissions peak as early as 2030 and comes to the conclusion that a hybrid policy can better help reach a carbon emission peak before 2030.

This article adopts the classical CGE model to simulate the impact of three different carbon emission reduction policies on China's macroeconomy. However, this model also has some limitations. Because the model is relatively simple, the conclusion is the impact of emission reduction policies on China's macroeconomy, rather than the specific industries. In the future, more complete data will be considered to analyze the impact of the emission reduction policies on the distribution of various factors and industry structures in China. In addition, since the model is static, in our future studies, we will explore the intertemporal dynamic CGE model and introduce the penalty mechanism for the non-timely performance of carbon trading and tax rebate mechanism of carbon tax into the model to compensate for the deficiencies of the current study and to develop a comprehensive policy support.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JS and CZ: data collection, data analysis, conception, and formal analysis; JS: writing the original manuscript; CZ: reviewing the manuscript. All authors agreed to submit to the journal.

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Evaluation of post COVID-19 energy poverty and global trading impact on energy affordability

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Energy poverty become a serious global problem after COVID-19 among the developing and developed countries that must have to be addressed to meet United Nations Sustainable Development Goals (SDGs). Moreover, the factors contributes to energy poverty have given little attention. The study aims to overlooked on the energy affordability and accessibility among the Europeans living in Energy poverty. Therefore, study mainly concerning on the effecting factors such as bilateral commerce, globalization, and the quality of bureaucracy that possibly affect energy poverty. The influence of bilateral commerce on energy poverty was investigated using many robust panel data approaches, including cross-sectional autoregressive distributed lag (CS-ARDL), common correlated effects generalized method of moments (CCE-GMM), and instrumental variable regression. Annual data utilizes from European nations (from 2000 to 2019). According to the econometric findings, bilateral commerce enhances energy accessibility while raising energy prices. Economic globalization was meant to raise energy costs and restrict fuel access for Europe's poorest citizens. Study suggested that bilateral trade should be assessed to ensure energy demand and supply conditions meet to keep the energy pricing in the afforadbale range especially among the low income families in the Europen countries. Across models, these results are consistent, allowing us to propose fresh energy accessibility and affordability conclusions in line with the SDGs.

KEYWORDS

energy poverty, energy prices, bilateral commerce, panal data approaches, energy affordability

Introduction

Over 1.1 billion people live in energy poverty (Tarekegne, 2020) and lack of access to clean energy, making the global scarcity of resources a major issue (Khandker et al., 2012; (Ahmad et al., 2019). More than two million homes in Spain and 9 per cent of households in Italy are affected by energy poverty, and a significant number of these households suffer

from health implications due to their living conditions (Khandker et al., 2012). As a result, the overall population's socioeconomic well-being and productivity are negatively impacted by energy poverty (Martinez & Ebenhack, 2008). The traditional energy sources of coal, charcoal, wood, cereals, straw and animal manure are still used by 2.8 billion people today (Ahmad et al., 2019). Bio dieasl cause pollition for indoor usage have substantial health consequences, particularly for women and children. Similarly, pollution from indoor sources (cooking meal and to keep warm the homes) is responsible for 2.8 million annual fatalities worldwide (Day et al., 2016). Developed countries' mainly focuse is on economical, ecologically green, social, and political concerns is energy poverty (Aristondo & Onaindia, 2018). In developing world, air pollution, food scarcity, housing poverty, climate change, water shortages and energy is the key challenge (Chapman & Okushima, 2019).

Energy dearth is when a person or household cannot meet their planned needs because they cannot afford to do so, and this leads to social dilemma in the society (Thompson, 1998). Energy poverty is also known as "fuel poverty" (Azomahou et al., 2005) and discribed as a lack of gasoline as "poor energy affordability" and "a wide phrase encompassing difficulties related to energy accessibility."

Energy poverty is linked to rising energy prices, low salaries, and building and gadget inefficiency (Shahbaz et al., 2018). The entropy approach calculates the energy poverty score. Moreover, energy poverty is exacerbated by tax regimes, insufficient investment in energy infrastructure, and a lack of awareness of energy efficiency (Javid & Sharif, 2016) and clarifying the introductory energy use stage to fulfill necessities. Thus, energy poverty is the non appearance of acceptable options for accessing a sufficient, cheap, consistent, and adequate supply of high-quality, environmentally friendly, and economically beneficial energy services (Jalil & Feridun, 2011) and due to these negative consequences, energy poverty has significant negative consequences for the well-being of humans, economic bustle, and the environment (Anderson, 2016). Energy poverty has been identified and many countries have seen it as one of the most pressing development challenges, including some advanced countries, for several years (Grossman & Krueger, 1995).

Despite the importance of energy poverty in social transformation has been underestimated. In a broad sense, it is accepted that energy is a necessary resource human development and plant's survivial (Muhammad, 2019). According to Tarekegne (2020) more than a billion people are living in energy poverty. Eliminating energy poverty is essential for social transformation and social wellbeing in developed, developing, and least developed countries. Thus, energy poverty is a unique form of poverty from the more common form of poverty caused by a lack of income (Tamazian et al., 2009). On the contrary, many aspects of life, including health, social inclusion, environmental quality, and mental well-being, are adversely affected by energy insecurity; energy poverty explains insufficient summer cooling. According to the Worldwide Energy and CO_2 Status quoted by (Sadorsky, 2010), China and India increased their carbon emissions by 85 percent of the United States. Asian countries are responsible of world carbon emission of 53%, and china is the biggest carbon emitter contributing 27% (9.8 billion tonnes of CO_2) to universal emissions where 15.% of global emissions (5.3 billion metric tons of CO_2) are attributed to the United States, the world's second-biggest emitter. Other hand india is the third largest contributor of the carbon emission of 6.8% (2.5 billion tonnes CO_2) to global emissions in 2017. China and India continue to use large amounts of traditionally polluting energy sources (such as coal, oil, and natural gas) at the price of ecological worth to achieve quicker rates of economic expansion and global competitiveness (Rao, 2019).

They have remained the world's top two and three carbon polluters. That's had major ramifications, encouraging developed countries like the US to reject commitments like the Kyoto Protocol of Japan in 1997 to meet any binding emission targets set by the UN Convention on Climate Change (UNFCCC) in 1992. When the Paris Agreement came into effect in 2015, it soon became a hot topic in the global climate change debate because of the perceived differences in interests and obligations between affluent and developing countries (Adams & Klobodu, 2018). United States blaming developing economies as significant polluters resulting climate change and attaining quicker economic expansion by massively deploying unsustainable energy in their use and manufacture.

As globalization and privatization accelerate, emerging and developing economies must use more cheap nonrenewable energy sources to maintain their 'competitive advantage,' which necessitates more expensive renewable energy sources This is the simple reason for the substantial deployment of murky energy in economic activities. Nonrenewable energy is cheap and available at any time for consumption and mining.

The European Union and its member countries have made it a priority in the past few years to solve the energy issue (Bélaïd & Youssef, 2017). According to European Commission estimates (2018) about 35 million people in Europe could not keep their homes warm in 2017 and in 2019 Clean Energy for All Europeans Package (CEP) with the aims to tacle the energy crisis and poverty in the Europen countries, alos energy efficiency and energy security connected to energy poverty, energy poverty is becoming a public concern. On the other hand, Latin America has a far higher rate of energy availability. Its 2016 access rate was 96%, greater than in Africa and South Asia (Azolibe & Okonkwo, 2020). Power availability has increased by over 50% but not by 90%, despite several Latin American countries having higher electricity. Despite this, only roughly 22 million peoplehave appropriate availability to power voltage, and over 80 million people cook with inefficient antique stoves using wood and charcoal. This study adds to the corpus of information about energy approachability and affordability, important for policy

mandates. Thus, the study provides new results and gave advice about trade profits. For instance, research shows how the market influences the entire price of the voltage energy and the resident's right to use basic energy needs. This study is mainly contributing in the SDG-7 (cheap and dependable energy), SDG-10 (reduce inequality), and SDG-13 (reduce poverty) are illuminated by these groundbreaking findings (climate action). Idleness and disparity reduced by Sustainable economic development and serious climate effect are priorities for the UN 2030 Agenda.

Trade-friendly policies should be prioritized in Europe to enhance income and maybe alleviate energy poverty suggested by researcher analysis. Europe's countries' institutions fail to offer inexpensive electricity to the region's poor. Second, reasonable estimates demonstrate that boosting trade in energy-related technology will help countries accomplish SDGs and reduce energy poverty by attractive bureaucratic value (and provide links for the decision-making process and plan development). Finally, this study examine significant policy possibilities for improving energy access and affordability in European Union.

Literature review

The association of energy poverty in Europe and economic crisis was studied by Halkos & Gkampoura, (2021) and findings shows that Scandinavian countries have the lowest energy poverty in Europe however unemployment and recession in the countries worsen the energy poverty. Apergis et al. (2022) findings based on the GMM estimates using education main variable and data collected from 30 developing countries from 2000 to 2016 shows education reduces the energy poverty. Drescher and Janzen (2021) conducted study on topic of energy poverty in Germany postulated that energy is mainly related to education, labor force, inefficient energy, and poor housing conditions.

Although European countries have emerged as the world's fastest-growing economy, approximately 23 per cent of the population lives in poverty (Milanovic, 2012; Niazi et al., 2019). China's setup is really in a deprived repair condition compared to other underdeveloped countries, such as India or Brazil. It resulted in the economy having to increase government monetary expansion assistance to eliminate poverty and inequality, as well as to address infrastructural needs to alleviate overcrowding and improve economic prospects.

Energy policies were initially investigated by Bouzarovski et al. (2012) in Europen countries where mainly focused on Bulgaria and reported that energy afforablity poorly managed in the country. Enegy poverty and policies were compared by Kyprianou et al. (2019) and measurement taken by the five EU countries (Cyprus, Spain, Portugal, Bulgaria, and Lithuania) to alliavte the energy poverty were discussed, where study Identified the weakness and strengths in the national energy policies towards the energy poverty and recommendation were drawn how to allievte the energy poverty in the country. Studies of a similar nature on a variety of factors that influence the quality of India's natural environment that are currently available on the internet. Economic expansion, according to Sun et al. (2022) is a contributing factor to environmental degrading practices and policies. One of the significant reasons for restricting the quality of India's natural pollution level, and this is one of the most significant causes for this. However, only a small number of European nations have discussed energy poverty in the past.

The prevalence of energy poverty in Romania ranges from 3.6 per cent to 16 per cent based on standard energy poverty indicators, while the multidimensional index estimates 10.5 per cent (Ottinger et al., 2014). An excessive energy burden, Bulgarian families have the highest incidence of energy poverty in the EU-27 nations. District heating of energy-deficient panels blocks of apartments exacerbates energy poverty in Croatia (Du et al., 2010). Energy poverty is prevalent due to the shortage of expenditure on building renovation and supplier-switch issues. The legacy of the previous economy is also blamed for energy poverty, which is a path-dependent phenomenon. Czechia has an estimated 17 per cent of its population living in energy poverty (Sterner & Damon, 2011). Author's also argued that energy poverty must be treated independently owing to the availability of governmental measures aiming at boosting energy efficiency and lowering family consumption.

European nations have an energy poverty problem aggravated by low incomes and squalid living conditions (Zhao et al., 2022). Many nations, particularly those with very vulnerable populations, have historically low operating and maintenance costs (Song et al., 2021), which suggest concealed energy poverty. To cope with energy poverty, people typically cut down on their energy use and unplug from the grid. The research on the lived experiences of the energy-poor shows that these individuals choose to meet their other fundamental requirements at the price of energy usage, for example. In addition, the energy-poor often cannot make large-scale financial expenditures to improve their homes' energy efficiency or renovate. There is such a crucial study gap in the literature that stimulates the question of whether we genuinely require more overall foreign aid or foreign energy assistance inflows in a growing economy like India to improve ecological quality.

Power rationing, frequent blackouts, and the failure of values to modernize buildings and services regularly are all repercussions of climate change. States in Southern Africa are investigating options ranging from transnational power exchange to regional and block electricity trading to address demands for hydropower (Zhang et al., 2021). In 2003, the incidence of energy poverty in the European Union was investigated and estimated that between 12.5 and 17.4 per cent of EU27 citizens fall within the category of "energy poverty. The authors rely on subjective energy poverty

indicators and certain house features from the ECHP dataset (Healy & Clinch, 2004).

Bouzarovski et al. (2012) performed a new EU27-wide energy poverty survey after nearly a century. The authors investigate subjective indices of energy poverty in four different situations and calculate a composite index. Three probabilistic models estimate the likelihood that families would experience energy poverty. A compound energy poverty indicator is an enhanced version of the benchmark indicator.

Micro-level Pan-European energy poverty research using objective measures is lacking for various reasons. The concept of energy poverty itself is ambiguous, which is one of the primary causes behind this. Energy Poverty Observatory (Barnes et al., 2011) has embraced the notion throughout the European Union (EU). A methodological challenge arises when it comes to direct energy poverty indicators and appropriate micro-level data. In the EU, there is no micro-data on the use of domestic energy and energy efficiency of the dwelling stock. There are several reasons for this, including the fact that the EU-SILC database is designed to track inequality and social inclusion in the EU.

Several studies have attempted to address the issue by using a typical data or specialized energy poverty surveys that are difficult to conduct throughout the EU. Enable-EU surveyed European energy usage in 2019 for this study. EU Horizon 2020 research and innovation funding program Enable-mission EU's statement is: " [Enable-EU] aims to study what influences people's decisions in three main consumption areas: infrastructure; heating and cooling; and energy (Kalisz and Aluchna, 2012). The study was aimed at 11 different European countries: Croatia, Belgium, France, Greece, Austria, Scandinavia, Czech Republic, Slovakia, Portugal, Ukraine, and the United Kingdom (United Kingdom). The dataset was accompanied by a report that summarized and compared the findings from the participating nations. All respondents were invited to complete the survey portions containing general and socio-economic questions. An important aspect of this study was asking participants to provide information on their income and energy use. These two factors were used to categorize them at risk of energy poverty. The wide range of nations included and the similarity of the macroeconomic issues, this dataset is especially useful for identifying determinants of energy poverty throughout Europe.

Cadoret and contrast the presence of the Phillips curve between fuel poverty and Average income in Europe using a panel of data from 27 European nations taken from Eurostat's EU-SILC survey for the period 2005–2018. Especially in southern and eastern Europe, they show that a decrease in energy poverty has been made feasible by rising living standards. Economic development alone will not always lead to reduced precariousness. Thus measures in favour of resource efficiency or family buying power must be implemented at the regional level. To test the Energy-Environmental Kuznets Curve hypothesis, (Rehman & Vinh Vo, 2020),use a panel dataset of over 200 nations for the period 2005–2019.

They discovered that increased economic development favours renewable energy output and a negative impact on coal-fired generation. Increased use of renewable energy also helps to level the playing field regarding income distribution. Emissions pollution is a significant societal issue in Europe, and it is expected to worsen in the next years as energy costs rise, economic misery persists, disparities widen, and climate change increases unpredictability. In Europe, between 25 and 130 million individuals are believed to be affected by EP (Bouri et al., 2020). In particular, 11.5% of EU families could not keep their homes warm enough in the winter months of 2014. EP, on the other hand, is not uniformly distributed socially or financially, according to several research. Low-income families (especially single-parent families), individuals with disabilities or long-term conditions, the economically inactive, and people in low-paying jobs all expertise above-average rates of EP in the social context (Khan et al., 2021).

Energy poverty has not been examined using a comprehensive approach considering its many elements concurrently. In addition, no previous research has looked at the impact of fiscal decentralization and national risks on energy poverty (Ahmad & Du, 2017), particularly in the context of Europe. Thus, the research aims to fill in the significant gaps in Europe's poevtry of the energy economy to help this country eliminate all forms of energy poverty. For now, Europe can ensure that all its citizens have electricity access. However, the country is trailing behind in clean energy since it has not yet eliminated its dependence on conventional non-renewable sources. Europe's goals to reduce greenhouse gas emissions are critical, and this research represents a significant step in that direction.

Data and methodology

Data processing

When describing the research population, we used chi-square tests to determine if the prevalence of EP (%) and the incidence of healthcare outcomes (percentage) had changed over the decades.

(Jena et al., 2021). There have been three major developments in searching for an extra-strong and long-term to fulfill the deficiency in energy, supply security, and environmental degradation. Many studies and investigations have examined whether adaptation and mitigation issues (Verhoef et al., 2015). Although energy poverty affects millions of people, it has received little attention. Lack of energy shows a clear picture of the inability of a household to receive and maintain levels for home use. Nonetheless, such problems continue to haunt people all across the world. To

recoup the energy poverty gap, many diagnostic indicators must be integrated to obtain a more comprehensive view of the transition. This paper will look at how bilateral commerce, globalization, and institutional quality might help the European Union relieve energy poverty. This analysis uses well-adjusted panel data for all 27 EU nations from 2000 to 2019. This study focuses on two parts of energy poverty: how expensive it is and how easy it is to get, all say that the authors got their data from the lowest 20% of the population's energy expenses quartile 1.

Econometric framework

Energy deficiency threatens population fitness, education, and development. According to SDG 7, modern and reliable energy sources must be made available to all by 2030 (Hornik, 2021). The European Commission's commitment is to reduce energy poverty and must be addressed immediately with targeted measures, which need extensive regional assessments. An appropriate assessment can assist in establishing and implementing policy. For this reason, the authors look at two important components of energy poverty: energy costs (affordability) and energy access (accessibility). Eqs. 1, 2 give the model's usual functional form of energy poverty affects both aspectsdimensions.

$$EXP_{i,t} = f\left(TRD_{i,t}, GDP_{i,t}, EGL_{i,t}, STR_{i,t}, BUR_{i,t}\right) \quad (1)$$

$$AFL_{i,t} = g\left(TRD_{i,t}, GDP_{i,t}, EGL_{i,t}, STR_{i,t}, BUR_{i,t}\right) \quad (2)$$

In our scenario, i denotes cross sections and t defines time dimensions, which is correspond to 27 EU countries from the years 2000–2019. There formulations of regression shows by Equations.

$$EXP_{i,t} = \delta_{1it} + \delta_{2it}TRD_{i,t} + \delta_{3it}GDP_{i,t} + \delta_{4it}EGL_{i,t} + \delta_{5it}STR_{i,t} + \delta_{6it}BUR_{i,t} + \alpha_i + \varphi_{it}) \quad (3)$$

$$AFL_{i,t} = \delta_{1it} + \delta_{2it}TRD_{i,t} + \delta_{3it}GDP_{i,t} + \delta_{4it}EGL_{i,t} + \delta_{5it}STR_{i,t} + \delta_{6it}BUR_{i,t} + \alpha_i + \varphi_{it}) \quad (4)$$

Expenses of energy and the ability to obtain it are both represented by EXP and AFL at the time t are substitute for energy poverty.

Vector δ 1 shows the unknown intercept, while the vector $\delta_1, \delta_2 \cdots\cdots\cdots\cdots.\delta_6$

The coefficient of all explanatory factors and φ it represent standard error, while αi marks the cross-section-specific term. Based on previous research by Curran and Eckhardt, (Porter, 1980), Each explanatory variable's predicted values are as follows: The recovery from energy poverty is likely to be helped by bilateral trade

$$\left(\delta_{2it} = \frac{\partial EXP_{i,t}}{\partial TRD_{i,t}}, \frac{\partial AFL_{i,t}}{\partial TRD_{i,t}} > 0\right), \quad (5)$$

However, the coefficient's value might fluctuate based on if a nation have a net trade.

GDP, economic globalization, and quality of institutions are also predicted to have an expected impact are all

$$\left(\delta_{3it} = \frac{\partial EXP_{i,t}}{\partial GDP_{i,t}}, \frac{\partial AFL_{i,t}}{\partial GDP_{i,t}} > 0\right), \left(\delta_{4it} = \frac{\partial EXP_{i,t}}{\partial EGL_{i,t}}, \frac{\partial AFL_{i,t}}{\partial EGL_{i,t}} > 0\right), \left(\delta_{6it} = \frac{\partial EXP_{i,t}}{\partial BUR_{i,t}}, \frac{\partial AFL_{i,t}}{\partial BUR_{i,t}} > 0\right), \quad (6)$$

respectively.

According to expectations, however, the Magnitude of the coefficient will change from one country to another due to disparities in the development of the economy, the permeability of the market, and the standard of institutions. As opposed to this, the projected mark of facilities trade is negative or modest because it does not immediately lessen poverty

$$\left(\delta_{5it} = \frac{\partial EXP_{i,t}}{\partial STR_{i,t}}, \frac{\partial AFL_{i,t}}{\partial STR_{i,t}} > 0\right) \quad (7)$$

According to a large body of literature (Porter, 1985), cross-sectional dependency is common in panel data. Due to the country's monetary or business interdependence, multiple unobserved shocks may be blamed and influence one or more countries. As a result, we begin our empirical part by examining how shocks influence all cross-sectional units. The author uses cross-sectional dependence test to do so.

Due to panel data's cross-sectional reliance, the unbiasing and compromised parameter consistency. However. When cross-sectional dependency was evident, the and cross-sectional Augmented Dickey fuller test CADF panel unit root tests were used to investigate the stationary aspects. Eqs. 5, 6 in Pesaran's paper theoretically represent this test.

$$\Delta Z_{i,t} = \varphi_i + \varphi_i X_{i,t-1} + \varphi_i \bar{Z}_{t-1} + \sum_{l=0}^{p} \varphi_{il} \Delta \bar{Z}_{t-l} + \sum_{l=0}^{p} \varphi_{il} \Delta Z_{t-l} + \mu_{i,t} \quad (8)$$

The cross-section averages are $\bar{Z}_{t-1}$ and $\Delta\bar{Z}_{t-l}$, respectively. CIPS statistics and values from the examination above were employed in the augmented CADF) test.

$$CIPS = N^{-1} + \sum_{i=1}^{p} CADF_i \quad (9)$$

For test statistics, CADF Eq. 9 shows I th module for cross-sectional in was provided by CADFi. The Caro & Sadr, (2019) cointegration method is used to continue the empirical investigation to elaborate on long-term phenomena between energy poverty and identify its elements. Using the unit root test, all variables are stationary by a combination of level and first difference. Second-generation cointegration is the name given to this method since it contains an error-correction mechanism

(ECM). Because it manages cross-sectional dependency and heterogeneity, the approach beats classical integrations in this regard. It uses four test statistics, two for group statistics and two for panel statistics (G t and G a) and (P t and P a), to determine the validity of the results.

$$G_t = \frac{1}{N} + \sum_{i-1}^{N} \frac{\alpha_i'}{\mathrm{SE}(\alpha_i')} \tag{10}$$

$$G_\alpha = \frac{1}{N} + \sum_{i-1}^{N} \frac{T\alpha_i'}{\alpha_i'(1)} \tag{11}$$

$$P_t = \frac{\alpha'}{SE(\alpha')} \tag{12}$$

$$P_\alpha = T\alpha' \tag{13}$$

There may be cross-sectional dependence in the panel data. Hence the researcher adopts a technique called CS-ARDL. This research describes the connection between variables like poverty in energy, bilateral trade, economic globalization, economic growth, services trade, and institutional quality. Although non-stationary and a combination of variables are involved, this strategy remains stable. Aside from endogeneity difficulties, the approach is also immune to the common problems with panel data (Alexander & Kent, 2022). The following equations are recommended for testing:

$$\Delta EXP_{i,t} = \phi_i + \sum_{l=1}^{p} \theta_{il} \Delta EXP_{t-l} + \sum_{l=0}^{p} \theta_{il} Z_{i,t-l} + \sum_{l=0}^{1} \theta_{il} \bar{W}_{i,t-1} + \varepsilon_{i,t} \tag{14}$$

$$\Delta AFL_{i,t} = \phi_i + \sum_{l=1}^{p} \theta_{il} \Delta AFL_{t-l} + \sum_{l=0}^{p} \theta_{il} Z_{i,t-l} + \sum_{l=0}^{1} \theta_{il} \bar{W}_{i,t-1} + \varepsilon_{i,t} \tag{15}$$

The describer uses the Dumitrescu–Hurlin (D-H) causality test to discover the connection between scarcity of voltage and its causes. This test is a strong way to deal with heterogeneity, and cross-sectional dependencies discussed earlier in this section. This method was made by (Pan, 2019) based on the granger non-causality test. You can see how the D-H panel's causality looks like a straight line in the below equations.

$$y_{it} = \alpha_i + \sum_{k=1}^{k} \gamma_i^{(k)} y_{i,t-k} + \sum_{k=1}^{k} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \tag{16}$$

Where insign represents the 27 EU countries at time t, I represent the discrete intercept, and I represent the coefficient slope, whose time dimension is not changed. Coefficient of regression and autoregressive parameter estimators, denoted by $\beta_i^{(k)}$ and $\gamma_i^{(k)}$. They are anticipated to differ between countries. There is no causal association under the null hypothesis, but there is causal affinity under the alternative hypothesis. The normal and standardized test data for the D-H test are as follows:

$$W_{N,T}^{HNC} = N^{-1} \sum_{i=1}^{N} W_{i,T} \tag{17}$$

$$Z_{N,T}^{HNC} = \sqrt{\frac{N}{2M}} \left(W_{N,T}^{HNC} - M \right) \rightarrow N(0,1) \tag{18}$$

where $W_{N,T}^{HNC}$ stands for average, $Z_{N,T}^{HNC}$ for standardised test statistic, and $W_{i,T}$ for individual Wald statistic.

Results and discussion

Descriptive statistics of variables

Table 1 shows the results of the first step in investigating the research variables' distribution and standard error. The most dynamic statistic is bilateral trade, with descriptive and inferential statistics of 20.8545 and 3.52, respectively. Even the levels of skewness, and their related probabilities, show that all variables are regularly distributed. Overall, there were no statistical outliers. Furthermore, the moment condition is unrelated when overall variables showed unit roots; null hypothesis for all panels is strongly rejected at conventional significance, alleviating some of this anxiety. Traditional information criteria demonstrate that PVAR 1) is the preferred model, and the validity of over-identification confirms by Hansen J-statistic, meaning that the instrument collection is adequate. The dynamics of interaction between the system's variables are complicated. PVAR cannot be easily interpreted without imposing identifying restrictions on the parameters by a raw coefficient. If the model is stable, an infinite-order VMA and error covariance matrix assumptions can be enforced.

Cross-sectional dependance test

A state can preserve power and self-interest as a functioning rational agent by the grand functionalist idea. According to Giordano, (2020) neo-functionalism sees the establishment of supranationalism within land-living and beneficial purposes for improved political and expansions of MKT. An ideology of regionalism as an alternate called intergovernmental, keeping national sovereignty while maintaining supranational links without handing up total power to regional institutions keep national sovereignty to maintain supranational (Borisoglebskaya et al., 2019).

Regional integration and regional collaboration are the heart of both ideologies. The experiment of post-World War II and post-Cold War soviet governments encouraged significant discussions about regional integration and cooperation is listed in Table 2.

People often use the terms "regional integration" and "regional cooperation" interchangeably, but they mean different things (Leal & Perez, 2009). While we first try to re-center national political centers on broader institutionalized platforms with shared terrestrial borders for political and economic purposes, the second step allows national identities to be saved for working together. Even though regional cooperation is good, more European international relations are driven by regional integration.

TABLE 1 Statistic description.

Variables	Obs	Mean	StdDev	Min	Max	p1	p99	Skew	Kurt
EXP	7,184	4.256	0.477	2.177	5.179	3.045	5.127	−0.583	3.528
AFL	7,167	16.514	1.269	12.878	18.235	12.938	18.238	−0.529	2.938
TRD	7,179	19.878	2.517	7.162	25.668	13.015	24.855	−0.567	3.949
GDP	7,187	10.693	1.242	7.985	15.264	8.372	14.886	1.392	5.023
EGL	6,803	4.284	0.023	4.215	4.333	4.214	4.331	−0.381	3.775
STR	6,804	0.489	0.574	0.083	3.032	0.101	2.814	2.652	9.279
BUR	7,184	3.261	0.815	0.211	4.120	1.012	4.102	−1.091	3.868

TABLE 2 Cross-sectional dependence test.

Variable	CD-test	*p*-value	Average joint	Mean ρ	Mean abs(ρ)
EXP	510.719	0.000	18.000	0.441	0.772
AFL	542.085	0.000	17.910	0.472	0.641
TRD	756.154	0.000	16.980	0.654	0.693
GDP	1,056.727	0.000	18.000	0.912	0.912
EGL	1,129.776	0.000	18.990	1.003	1.001
STR	640.767	0.000	19.990	0.571	0.612
BUR	34.185	0.000	18.000	0.032	0.041

TABLE 3 Panel unit root testing.

Test	Variable	Level	First difference
CIPS test	EXP	−6.078	−6.564***
	AFL	5.443***	10.008
	TRD	−14.489***	−9.212***
	GDP	−3.173***	−1.784**
	EGL	−84.92***	82.916***
	STR	1.715	−4.455***
	BUR	45.678	82.914*
	EXP	−5.719***	−26.729***
	AFL	1.434	−39.171***
	TRD	−12.656***	−46.478***
CADF test	GDP	−5.041***	−31.017***
	EGL	−84.09***	−84.079***
	STR	2.021	−28.113***
	BUR	46.204	49.305*

***, **, * indicate the level of significance at 1, 5, and 10%, respectively.

We discovered a clear link between energy poverty and unfavourable health consequences as listed in Table 3. The economic crisis had a greater impact on the mental health of this group, notably in the area of depression. Persistent thermal unpleasantness has been shown to have a negative impact on mental health, as have fears that the cold will harm one's health and wellbeing, as have concerns about high energy costs, as well as the fear of (or experience with) debt. Household financial debt and home instability are linked to worse mental health and health care utilization in people with EP. In the EU, as well as some of the HSVc, there was an upsurge in both scenarios during the financial downturn. In several EU nations, unemployment numbers rose due to the economic crisis. Several scholars have shown that long-term labour participation can have adverse effects on health.

These effects are exacerbated in countries with less developed employment rate protection devices and without active labour-market programs, as in HSVc. Finally, welfare cuts in the healthcare organizations ranged from cool and solidified to drastic cuts. Italy, France, Tuscany, and Portugal were the most severely afflicted HSVc nations, with Greece coming in second. These factors might have a role in the reported link between energy poverty and worse medical outcomes and the increase over time.

Base model

To give a clearer picture of proposals on how countries in EU might use regional cooperation to combat energy shortage and achieve the SDG seven target of "universal access by 2030," We've

TABLE 4 Panel cointegration empirics.

Test	Model-1		Model-2	
Westerlund cointegration	Statistic	*p*-value	Statistic	*p*-value
Gt	−12.988***	0.000	−5.028***	0.000
Ga	−26.798***	0.000	−6.485*	0.060
Pt	−86.791***	0.000	−58.28***	0.000
Pa	−12.573***	0.002	−5.612***	0.003
Pedroni Cointegration	t-statistics	*p*-value	t-statistics	*p*-value

divided our policy approvals into two categories. We present a policy roadmap for countries to follow Within European natons It could be better positioned for power cooperation and trading. We identify significant emphasis areas for regional collaboration within countries in the region in the second category. Study propose a technological innovation that shows how north-south links might be enhanced and leveraged for better ends.

The Westerlund cointegration test is the best option, even when there is a serial correlation, structural breaks, heteroscedasticity, and cross-sectional dependence among the cross-sectional units. Cointegration is found in both models, and the null hypothesis that there is no serial correlation is ruled out. This shows that energy costs, fuel availability, and technology have important long-term relationships with their respective determinants. The researchers use the cointegration test to evaluate the empirical data's reliability, which validates the long-term Johansen co - integration connection between variables as shown Table 4.

In a framework regions electricity data use to make it cohesive, the regional cooperation must go beyond export and import in power. To drive national policy cooperate with a system and create homogeneity in nation's member. Strive for consistency when comparing for essential statistics such as adequacy, movement in products and services, and releases of carbon. Given the ambiguity of the UN SDG 7, EU regional bodies must agree on minimum standards for member nations' sufficiency (kWh/individual/year), mobility (kWh/individual/year for individuals or kW/year for installed generation capacity), and emissions (tCO_2/individual/year).

This is vital to avoid kingdoms in the region using different criteria, which would deadlock progress toward the 2030 objective. To participate in energy peers and trading in different federations promote regional competition by liberalizing electricity markets. For regional power supply in the market, make flexible agreements, rather than bilateral contracts, and the system trying to balance the higher demand by power pools as shown Table 5. Furthermore, viable regional energy markets benefited all players and necessitated the establishment of legislation prohibiting unfair state aids that favor some national generation corporations over others (Saghiri et al., 2017).

When considering the social consequences of decarbonization, the ability of households to satisfy essential energy demands, dependable and cost-effective, is crucial. As part of the low-carbon transition, consumers must engage in building renovations and purchase low-carbon equipment, such as heat pumps. Additional finances to pay higher upfront capital expenses may be erratic and dangerous for low-income people (Barykin et al., 2021).

The efficiency of energy will save households money over a lengthy time; the higher upfront costs may put a further financial strain on low-income families that cannot buy energy-efficient appliances, homes, or cars, hence exacerbating energy poverty. Binary displays measure Decarbonization's effects on energy spending: "the proportion of energy expenditure for fuels and electricity in household income" and "the share of energy expenditure for fuels, electricity, and energy equipment in income" by decile cluster. Energy-related spending for petroleum, power, and energy apparatus by EU republic, PRIMES model for decarbonization scenarios,3 HBS data to allocation national-level energy expenditure to family deciles, and total income per decile, as assessed by GEM-E3-FIT.

Energy prices fluctuate when the proportion of income spent on energy varies across the Member States and socioeconomic brackets. In 2015, 21% (on average across EU countries), this indicator was assessed at 21% for the lowest decile and varied between 4 and 50% in the different Member States (Sacks et al., 2020), while the indicator falls to an average of 3% of income in 2015 for high-income households in all Member States. Eastern Europe are more at risk than those of Western Europe countries, group of low income utilize more income to energy resources, For example, low-income households in Eastern Europe face substantial difficulties due to high energy usage compared to their income, according to the data. On the other hand, households in the Netherlands, Sweden, France, and Denmark spend a modest percentage of their income on energy-related costs BY Netherlands, Sweden, France, and Denmark.

Families with lesser income are more affected by variations in power prices because they spend a huge amount of income on power supply resources. EU Member states vary this situation, as evidenced by the wide range of income deciles across nations, middle and low-income households realms devote extra than 15% of their income on energy-related expenses (e.g. Bulgaria, Estonia and Lithuania).

There are both long- and short-term coefficients for interdependencies between the variables in the research in Table 6. European union nations' EP is influenced by factors like TRD, GDP, EGL, STR, and BUR. EP in the European Union nations is measured in two ways: affordability, which is decided by the energy costs of those in the bottom 25% of the demographic, and accessibility, which is defined by the

TABLE 5 Panel Empirics using CS-ARDL Estimations.

Variables	Model-1 (energy expenses)			
Short-run estimates	**Coefficient**	**z-statistics**	**Coefficient**	**z-statistics**
ECT	0.000***	3.991	−0.085***	−6.601
TRD	0.013**	1.693	0.083*	1.951
GDP	0.314***	2.522	0.012**	0.432
EGL	0.076*	0.074	0.013*	0.049
STR	−0.063*	−0.842	−0.042*	−1.531
BUR	0.642***	5.601	−1.769**	−6.063
Constant	0.279***	13.023	0.036***	8.222
Long-Run Estimates				
Lagged e.poverty	−0.912***	−36.862	−1.089***	−83.741
TRD	0.039***	2.433	−0.082**	−1.881
GDP	0.622**	4.164	0.013*	0.473
EGL	0.629*	0.061	0.046*	0.012
STR	−0.089	−0.933	−0.059**	−1.891
BUR	−8.107***	−6.025	−0.974***	−6.392
Constant	0.213***	10.762	0.035***	8.053
N	25	–	25	–
CD test	80.69***	–	22.25***	–
R-squared (MG)	0.99	–	0.89	–
F-Statistic	5.76	–	14.33	–

TABLE 6 Panel Empirics using CS-DL Estimations (Mean Group).

Variables	Model-1		Model-2	
	Coefficient	**z-statistics**	**Coefficient**	**z-statistics**
TRD	0.014**	2.471	0.184**	4.354
GDP	0.198**	2.245	−0.463*	−1.622
EGL	0.112***	4.834	0.869***	5.213
STR	−0.121**	−2.286	−1.354**	−2.464
BUR	−0.028	−0.757	0.099	1.053
Constant	0.149**	10.993	0.575**	6.282
N	27	–	27	–
CD test	154.59***	–	21.74***	–
R-squared (MG)	0.98	–	0.98	–
F-Statistic	4.25	–	4.99	–

availability of fuels and equipment in the kitchen. European Union nations' bilateral commerce has climbed by 1 per cent over the last year, which has resulted in an increase in energy costs of 2.3 and 4.6%, respectively.

B2B trade positively impacts the affordability of EP, meaning that bilateral commerce does not aid European union nations in their recovery from EP, according to these findings. As a result, energy prices for the region's lowest 20% of the population are somewhat higher due to bilateral commerce in these linked nations.

In 2015, the energy expenditure share increased by 5.9 percentage points across income, including power-related equipment (including energy appliances, heating devices, and autos). In member states, high-income and

low-income groups have a difference in energy expenditure on transportation. High-income people have more expenses on energy use for transportation demonstrated by the HBS database. High-income purchase more expensive appliances and luxurious atoms. Middle and more income groups frequently buy classy energy equipment, highly efficient appliances, and luxurious items compared to low-income persons. As a result, when energy and transportation equipment expenditures are included, the stake of income spent on energy amenities by the wealthiest decile rises from 3 to 9%.

In the Reference scenario, the returns of families rise quicker than values of power, the average contribution of dynamism spending income falls across EU nations and income deciles from 2015 to 2050. Energy price is reduced slightly in low-income families as expenditure grows slower than their income. Indicator two shows the same outline, with energy expenditure share falling by 1.5% across the EU States and socioeconomic levels from 2015 to 2050.

Decarbonization necessitates large changes in household energy spending and subsequent distributional adjustments. Increased energy consumption across EU countries would result from high carbon pricing, owing to higher energy product prices. In 2050, energy Spending Indicator one rises by around 1 percentage point from Orientation in the EU, as fuel and electricity payments rise even though income falls. The biggest upturns are recorded in low salary categories, representing that the most vulnerable populations may face greater difficulty purchasing essential energy services, increasing the danger of deficiency (Lu et al., 2020; Ullah et al., 2021).

In the Reference scenario, Magnitude differs extensively by lower impacts with the highest values for Indicator 1. Apart from these two main variables, The TRD and GDP per capita account for 12.7 percent and 7.30 percent of total shock volatility in other variables in the row (7). Surprisingly, the role of GDP per capita as a shock receiver and transmitter is so important. Decreased future output levels can come from increased oil price volatility as a secondary major shock transmitter and GDP as a secondary prominent shock intake. This finding supports Table 4, column 7) shows significant shocks to GDP per capita and biofuel, 7.5 and 6.0 percent of overall shocks. Other factors in the row account for 12.7 and 7.30% of overall shock volatility (7). It is remarkable how crucial GDP per capita is as a shock receiver and transmitter. Increased oil price volatility is a second major shock transmitter, while GDP is a second major shock receiver. Other factors in the row account for 12.7 and 7.30% of overall shock volatility. It is remarkable how crucial GDP per capita is as a shock receiver and transmitter. Increased oil price volatility is a second major shock transmitter, while GDP is a second major shock receiver. Oil price impulsiveness hurts GDP and causes many GDP shocks (Hossain et al., 2020).

Robustness analysis

Meanwhile, a prominent shudder intake in biofuel and stable with those of, who claimed that biofuels began to follow the price dynamics of crude oil as a result of policy intervention. Explained the results of the GDP jolt to biofuel for OECD countries. For Europe, (Matsuda et al., 2019), for emerging countries, for Central and South America, and for China all stressed the importance of income in determining biofuel consumption. The detail could clarify this conclusion that as GDP per capita rises, so does the pecuniary viability for countries to develop, maintain, and promote high-tech and cleaner biofuel policies and investment (Bučková et al., 2019). Furthermore, the outcomes are consistent with (Cai & Lo, 2020). They demonstrated that, regardless of the economy, instability in oil prices has an adverse and meaningful impact on GHG emissions. Tremors in oil cost use alternative or green energy sources to reduce oil consumption, resulting in reduced CO_2 emissions.

Table 7 demonstrates the robustness test using CCE GMM and IV regressions. It is consistent with previous studies, such as, which showed that free trade increases emissions intensity and, as a result, energy carrier consumption. This implies that these economies need to increase trade and expose their local markets to international competition. As a result, local businesses may benefit from global trade and import as much as feasible at a reasonable price.

Several changes occurred throughout the study period despite the implications of the preceding findings. Increased linkages among global financial markets, for example, can be defined as a progressive progression. Other phenomena, such as commodity price booms, may be properly classified as bursts that have since faded. Additionally, the evolving attitude toward climate change over the last few decades may impact the relationship between energy and food prices.

Our baseline specification is PVAR (1), which produces variance decompositions of mistakes in 10-years-ahead forecasts of 10-years volatility. The results of the diagnostic tests show the portrayal offers the finest goodness-of-fit and thus the suitable estimates of instability spillover guides. However, in this paragraph, we conduct many tests to ensure that the results are stable under different PVAR model settings.

First, we use (Scherbakov & Silkina, 2019) spillover index to predict distances ranging in the period from one to ten, then present the minimum, maximum, and median indices. Since the sample size is less, Panel B has a wider confidence interval since more observations are omitted when using higher-order criteria. The results in less exact estimations. Third, it is possible to make the case that the strong link between agricultural energy use and CO2 emissions affects the outcomes. Eliminate the CO2 emissions from the PVAR system and replace them with trade openness and financial development to check the

TABLE 7 Robustness check with CCE GMM and IV regressions.

Variables	CCE GMM		GMM IV regressions	
	Model-1	Model-2	Model-1	Model-2
TRD	0.01910*** (3.59)	0.0522** (2.241)	0.065*** (11.04)	0.8767*** (13.122)
GDP	0.05797*** (4.81)	−0.1427*** (−2.766)	0.058*** (5.332)	0.1639*** (3.031)
EGL	−0.0358*** (−2.52)	0.2187*** (3.01)	1.097** (2.320)	2.3968* (0.521)
STR	−0.0429*** (−1.88)	−0.2361** (−2.819)	1.168*** (11.78)	6.8057** (6.871)
BUR	−0.04156** (−2.79)	0.3666** (3.312)	−0.288*** (−24.72)	5.4328*** (54.970)
Constant	−0.3518** (−0.37)	3.8366* (0.371)	−1.853** (−0.870)	67.096*** (3.2310)
N	28	28	28	28
Wald Chi^2-Statistic	39.55	5.61	767.46	3,895.79**
Hansen overidentifying restriction	–	–	73.858**	33.627**
Endogeneity test	–	–	169.71**	76.24**

sensitivity. The volatility reduced-system index shows a discount of the spillover conclusion to one-third, with a maximum of 7% in 2001. Nonetheless, if CO2 emissions were left out of the equation, the EEEE system's results would be impacted. ARDL model settings do not affect the Multidimensional povertyindex. Additionally, the baseline model proposes a more conventional estimate of the time-varying spillover effect (Zhabko et al., 2019).

Conclusions and policy discussions

The research study investigated the impact of global trading impact on energy poverty in European countries. As a vital component of trade, energy is rarely discussed concerning energy poverty, trade products, and rising levels of economic globalization. For the individual, household, and national reasons, energy can be considered the lifeblood of all economic sectors. Several studies have looked into the impact of energy poverty on trade and other socioeconomic factors (e.g., well-being, gender, and education). However, there is a lack of research on the precise effects of bilateral commerce and economic globalization on energy poverty. The empirical data lead to some fascinating and persuasive conclusions. Our key finding is that bilateral trade throughout Europe has a significant negative impact on energy costs and accessibility. On the one hand, greater trade volume may hasten economic activity and produce moderate inflation due to economic openness, raising utility and energy costs for low-income households. On the other hand, bilateral trade may make innovative items, energy, and technologies more accessible in all European countries. Cooking technology and fuel accessibility for low-income groups may improve, yet these may become too expensive and out of reach for the poor. Economic globalization's robust analysis and empirical evidence support this conclusion, arguing that more economic openness has a one-sided benefit of reducing energy poverty through increased accessibility. Only the middle and upper classes can afford the most advanced equipment and technology that offer greener and cleaner energy. Economic globalization and bureaucratic quality may moderate energy poverty, as these elements are directly linked to policymaking and trade laws.

Policy discussions and future directions

The empirical findings suggest that bilateral commerce between European nations should be reconsidered. All countries profit equally, persons in the lowest income quartile are taken into account, and environmental impact is avoided. To fulfill the United Nations' Sustainable Development Goals (SDG-7: cheap and clean energy; SDG-8: foreign direct investment in green technology; SDG-9, industry, innovation, and infrastructure; SDG-13, climate action), new initiatives and regulations may be necessary. To reduce environmental impact, the Sustainable Development Goals firmly focus on affordable, clean energy, emphasizing renewable and greener energy accessibility and affordability. Given that many people still lack access to cleaner energy (electricity and equipment), policymakers must take initiatives to facilitate bilateral trade through synchronized and controlled rules governing product export and import. It is critical to make electricity more accessible to households.

It is also important to examine the large levels of immigration in European countries, which necessitates a variety of benefits and resource allocation. As a result, restricting trade or economic globalization may not be a viable option because ethnic and cultural variety encourages trade and business activity in the context of the

country's business and trade legislation. However, it is vital to note that the large benefits of immigration are likely to be eroded by new globalization policies and trade laws.

In conclusion, the extensive data is collected from the European countries underline the need to increase access to new energy sources and equipment while keeping costs low. Energy accessibility may have a broader impact on socioeconomic results and long-term growth if policies are developed to address exports and imports. Integrated efforts to create a governance structure and provide practices that build community groups to enable them to improve cleaner energy accessibility could be among the policy initiatives. It is especially true for persons living in rural regions and those in the lowest income quartile. As a result, this impact may help people see energy poverty as a problem that affects both developing and growing countries rather than being limited to a single region. This research could be useful in developing a policy framework to deal with bilateral trade, economic globalization, and energy poverty.

According to the study, policy-directing programs in trade (export and import structure) that focus on contemporary energy accessibility and involve key stakeholders could lead to implementing strategic measures to mitigate environmental externalities. The current analysis has one caveat: we only looked at bilateral commerce and economic globalization as potential avenues for influencing energy accessibility and affordability. Although the literature lists various ways to solve energy poverty, it is not possible to investigate all of them due to a lack of data. Income inequality, general economic complexity, product diversity, and ethnic diversity should be investigated further to see how they affect energy accessibility and affordability. Future research should also concentrate on the impact of trade and institutional governance on energy poverty in developing economies like Africa.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ES, Conceptualization, methodology, and OS software validation, Drafting and editing ES.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
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Sustainable Energy Recovery From the Malaysian Coal Bottom Ash and the Effects of Fineness in Improving Concrete Properties

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The particle size (μm) of coal bottom ash displayed significant effects on the concrete engineering properties. This research aims to assess the improvement of engineering properties of concrete containing CBA (fineness: 75 and 100 μm) known as Mix 75 and Mix 100, and to optimize the percentage of coal bottom ash as supplementary cement materials in concrete. The physicochemical properties of coal bottom ash were analyzed using X-ray fluorescence, X-ray diffraction, particle size distribution (PSD), and a scanning electron microscope. The strength of concrete was determined based on workability and compressive and splitting tensile strengths. The concrete strength improvement was optimized by response surface methodology. The results of the study showed that coal bottom ash was rich in silicates based on the highest peak at 45°. The scanning electron microscope images showed that coal bottom ash has few cenospheres and components of irregular-shaped char particles. The splitting tensile strengths in 28 curing days gradually decreased with an increase in coal bottom ash. The optimal percentage of coal bottom ash in Mix 75 is equivalent to 6% within 45.4 curing days producing 40 MPa of compressive strength. Meanwhile, the optimal percentage of CBA in Mix 100 is equivalent to 12% within 56 curing days producing 50 MPa of compressive strength. The future works needed to extend the experimental observations are the economic analysis and effect of the greenhouse reduction on the usage of CBA in building infrastructure.

Keywords: Coal bottom ash, concrete strentgh properties, compressive strength, splitting tensile strength, physicochemical properties, Economical optimization

INTRODUCTION

Coal bottom ash (CBA) is a component waste material of coal combustion produced by coal-generated power plants. It is rich in heavy metals (Beddu et al., 2020a; Kamal et al., 2019) and classified as scheduled waste (Cho et al., 2013; Odimegwu et al., 2018; Sun et al., 2020). Some of the Malaysian coal-generated power plants are Tanjung Bin in Johor Darul Takzim (2,100 MW), Jimah in Negeri Sembilan Darul Khusus (1,400 MW), Kapar in Selangor Darul Ehsan (2,420 MW), Manjung in Perak Darul Ridzuan (2,295 MW), Mukah (270 MW), PPLS (110 MW), and

Sejingkat (100 MW) in Sarawak Bumi Kenyalang (Oh, 2010; Beddu et al., 2021). The electricity generations in Malaysia from these power plants produce CBA waste ranging from 9–250 tons/day (Beddu et al., 2020a), in addition to the other household waste generated about 19,000–3,000 ton/per day in Malaysia (Ahmad and Ayob, 2015). Concrete contains 12% ordinary Portland cement (OPC) and up to 80% of aggregate by mass (Muda et al., 2013; Ahmad et al., 2021a). Aggregate is any particulate material that can be either natural (gravel, crushed stone, and sand) (McNeil and Kang, 2013) manufactured (slag, a mixture of metal oxides and silicon dioxide from metal mining) (Ahmad et al., 2020), or recycled waste materials (recycled concrete (Jian and Wu, 2021) geosynthetic aggregates (Robinson and Howard, 2021), diapers polymers (Mohamad et al., 2017; Abd Manan et al., 2021a), and CBA (Yahya et al., 2017; Beddu et al., 2018)). Marine aggregate requires acid wash to remove sodium that will corrode the concrete structures (Wang et al., 2021). Aggregate from desserts has round grain structures due to wind erosion, and hence, it is incapable of binding to concrete. Therefore, aggregate mining from riverbeds and quarries was utilized at the rate of 10–11 billion ton per year contributing to adverse impacts on the environment (Abd Manan et al., 2019). The OPC is the binder material in concrete. CBA is commonly used as an aggregate instead of SCM due to its natural raw size similar to aggregate (Abd Manan et al., 2021a). To be used as SCM, CBA requires a grinding process to obtain the filler size. Nevertheless, CBA can be sieved to simulate the fineness of OPC. The physicochemical properties of CBA are in good association with OPC (Beddu et al., 2020b; Singh and Siddique, 2015), making it a good alternative material while maintaining and/or improving the engineering properties of concrete. Mass production of CBA as mentioned previously guarantees a sustainable construction material (i.e., aggregate and SCM) in the industry converting waste to green material.

Table 1 presents comparison studies on concrete property improvements using CBA with the current research. The application of CBA was reported to be in terms of SCM (particle size: 45, 75, and 100 μm) and sand replacement material (particle size: 4.75 mm).

Singh and Siddique (2015) applied CBA (w/c ratio: 0.55) at different volumes (C1: control mix, C2: 30% CBA, C3: 50% CBA, C4: 75% CBA, and C5: 100% CBA) as sand replacement material in normal concrete. The compressive strength improvement at 7 days was achieved at 94.6% (C2), 91.0% (C3), 86.3% (C4), and 84.8% (C5) more than the compressive strength of C1. The compressive strength improvement at 28 days was achieved at 34.4% (C1), 38.0% (C2), 44.3% (C3), 52.9% (C4), and 45.0% (C5) more than the compressive strength at 7 days. The exact figures on compressive strengths, however, are not mentioned. As sand replacement material, the particle size of CBA used was higher, equivalent to 4.75 mm. Khongpermgoson et al. (2020) used CBA (w/c ratio: 0.25) at different volumes (0, 15, 25, 35, and 45% of CBA) as SCM in high-strength concrete. The authors reported that the compressive strengths of 0%, 15%, 25%, and 35% CBA were more than 55 MPa. However, the compressive strength for 45% CBA was lower than 55 MPa. The CBA particle size was 45 μm. Kamal et al. (2021) studied the effect of CBA fineness (45, 75, and 100 μm) at different water-cement ratios (w/c: 0.40, 0.45, and 0.50) as SCM in normal concrete.

The optimal compressive strength obtained was 30 MPa (75 μm, w/c 0.45) and 32 MPa (100 μm, w/c 0.50) for 10% and 15% CBA, accordingly. In the application of high-strength concrete, the compressive strengths used by Khongpermgoson et al. (2020) (>55 MPa) and Mohamad et al. (2018) (50 and 61 MPa) were comparable regardless of the materials used. The compressive strength from CBA as SCM by Kamal et al. (2021) was 28 and 33 MPa. Sachdeva and Khurana (2015) investigated

TABLE 1 | Review studies on concrete properties.

Material	Water cement (w/c) ratio	Function	Type of concrete	Particle sizes	Compressive strength (MPa), 28 days	Splitting tensile strength (MPa), 28 days	References
CBA	0.45	Sand replacement material	Normal concrete	4.75 mm	C1 34.4%, C2 38.0%, C3 44.3%, C4 52.9%, and C5 45.0% over 7 days' compressive strength	n.a.	Singh and Siddique (2015)
CBA	0.25	SCM	High strength concrete	45 μm	0, 15, 25, and 35% >55	n.a.	Khongpermgoson et al. (2020)
CBA	0.40 0.45 0.50	SCM	Normal concrete	45, 75, and 100 μm	10% CBA (75 μm, w/c 0.45): 30 15% CBA (100 μm, w/c 0.50): 32	n.a.	Kamal et al. (2021)
CBA	0.38	Fine aggregate	Normal concrete	4.75 μm	0% (47.92), 10% (47.45), 20% (46.52), 30% (45.92), and 40% (39.59)	n.a.	Sachdeva and Khurana (2015)
CBA	n.a.	Partial substitute of cement	Normal concrete	2 mm	Std (40.9), 5% (40.38), 10% (40.24), 15% (33.57), and 25% (29.13)	n.a.	Kurama and Kaya (2008)
CBA Fineness	0.47	SCM	Normal concrete	75 and 100 μm	15% CBA (75 μm): 35 15% CBA (100 μm): 33 Optimal duration 6% CBA (75 μm, 45.4 days): 40 12% CBA (100 μm, 50.7 days): 50	The splitting tensile strengths gradually decreased with an increase of CBA	Current research

TABLE 2 | Mix proportion for Mix 75 and Mix 100 CBA replacement.

Mix 75 and mix 100	OPC (kg/m^3)	Percentages of CBA replacement (%)	CBA (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	W/C
CM	323–340	0	0			
5CBA75 5CBA100	323	5	17			
10CBA75 10CBA100	306	10	34			
15CBA75 15CBA100	289	15	51	515	1,385	0.47
20CBA75 20CBA100	272	20	68			
25CBA75 25CBA100	255	25	85			
30CBA75 30CBA100	238	30	102			

the BA as a sand replacement to produce an M40 concrete mix and investigated the compressive strength. The fine aggregates were replaced with coal BA by 10, 20, 30, and 40%. An obvious decrement was noted when BA was used up to 20%. Therefore, 20% is considered the optimum replacement percentage for this study. Kurama and Kaya (2008) observed that the compressive strength improved by 5% greater than the control concrete mixture at 56 days of curing.

The current research presents the effects of Malaysian CBA fineness on concrete property improvements. Compared to previous studies, the current research takeaway presents optimization studies of 15% CBA application (0.47 w/c, 75 and 100 μm of particle size) as SCM in concrete technology. In addition, concrete strength evaluation such as compressive strength in the current study was further explored with an addition of split tensile strength. This research is one of the concrete technology innovations promoting United Nations Sustainable Development Goals nos. 7 (affordable and providing clean energy) and 12 (responsible production and consumption) (Kurama and Kaya, 2008).

MATERIALS AND METHODS

Sampling Location

The CBA samples were collected from Malaysian power plant, oven-dried for 24 h, and ground and sieved to 75 and 100 μm. The material engineering properties of CBA including identification of oxides elements, crystallinity, particle size measurement, and observation of structural morphology of CBA were described by Abd Manan et al. (2021a). Our study complies with relevant institutional, national, and international guidelines and legislation.

Experimental Characterization

The samples were prepared in triplicates for each heavy metal, oven-dried for 6 h to remove moisture, and ground and sieved to 45 and 75 μm. The sieved samples were prepared in pellet form using a pressed pellet technique. The physicochemical properties of ash samples were analyzed using X-ray fluorescence (XRF), X-ray diffraction (XRD), particle size distribution (PSD), and a scanning electron microscope (SEM). The XRF analysis (RaynyEDX-700/800, Shimadzu Corporation, Tokyo, Japan) was conducted to determine the chemical oxide content in BA. The XRD analysis was conducted using Xpert Pro PANalytical to determine the amorphous state of BA. The sample was prepared in powdered form. The PSD was carried out using a particle size analyzer. The structural composition of BA was observed and recorded using a SEM (ZEISS GeminiSEM 500, Oberkochen, Germany).

Workability and Properties of Concrete

The mix design process was based on the method of the trial mix, the test mixes were prepared based on the Department of Environment (DOE, BS EN 12350-2) method guidelines European standard (2019; 12350), cited by Abd Manan et al. (2021b), and the result was taken from an average of three samples. The 28-day strength target was 30 MPa for various mixture groups. CBA was used with a maximum size of fine aggregates equivalent to 4.75-mm (ASTM C33/C33M). Sieve analysis tests (75 and 100 μm) were conducted on fine aggregates. Fine aggregates were dried in the oven for 24 h at 100°C before mixing in the concrete mixture. The mix ratio for CBA (mix 75: 75 μm and, mix 100: 100 μm) concrete including control mix (CM) is shown in **Table 2**. The blends have six different CBA percentages, which are 5, 10, 15, 20, 25, and 30%, respectively. These percentages were added to the experiment by referring to the trend of the previous study on cement replacement content.

The workability of the freshly made concrete mix was assessed via a slump test (BS-EN 12350-2:2009, slump cone). The goal for the slump test was 180 mm. The indication of workability is shown in **Table 3**.

The compressive strength (MPa, BS EN 12390-3:2002, cubes, 100 m^3) and the splitting tensile strength (MPa, BS 1881: Part 117:1973, cylinders, 150 mm Ø × 300 mm high) of concrete were conducted using a universal testing machine (UTM).

TABLE 3 | Workability, slump, and applications.

Degree of workability	Slump (mm)	Applications
High	100–178	Sections with congested reinforcement
Medium	50–100	Manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibrations
Low	25–50	Foundations with light reinforcement. Roads vibrated by hand-operated machines
Very low	0–25	Road pavement and roads vibrated by power-operated machines

TABLE 4 | Process variables and coded factors.

Process variables	Coded factors	Units	Type	Low actual	High actual	Low coded	High coded	Mean	Standard deviation
Curing days	A	Day	Numeric	3	56	−1	1	29.51	17.64
CBA	B	%	Numeric	0	30	−1	1	15.00	9.99

Model Optimization

Model optimization was conducted using a central composite design (CCD) with a second-order polynomial equation (**Eq. 1**) in RSM using the Design Expert® software (Version 12). Optimization is required to assess the link between process variables, namely, curing days (day) and CBA composition in concrete (%) with the response variable, compressive strength.

$$Y = \beta_0 + \sum_{i=1}^{k}\beta_i \cdot x_i + \sum_{i=1}^{k}\beta_{ii} \cdot x_i^2 + \sum_{i \le j}^{k}\sum_{j}^{k}\beta_{ij} \cdot x_i \cdot x_j + \ldots + e, \quad (1)$$

where

Y = predicted response variable

β = regression coefficient

k = number of factors or process variables in the experiment

e = random error.

The ranges of process variables [curing days (day) and CBA (%)] and coded factors [curing days: 3 (−1) and 56 (1); CBA: 0 (−1) and 30 (1)] are shown in **Table 4**. The percentages of errors between experimental and predicted values of compressive strengths were evaluated using **Eq. 2**.

$$Error\ (\%) = \left|\frac{Experimental\ Value - Predicted\ Value}{Experimental\ Value} \times 100\%\right|. \quad (2)$$

RESULTS AND DISCUSSION

The physicochemical properties of ash samples were analyzed using X-ray fluorescence (XRF), X-ray diffraction (XRD), particle size distribution (PSD), and a scanning electron microscope (SEM).

The XRF analysis showed the chemical oxide content in OPC, FA, and CBA (45 and 75 μm), and the selected properties of FA (class F and class C according to ASTM 1994) (**Table 5**). The chemical oxides were silicon dioxide (SiO_2), magnesium oxide (MgO), sulfur trioxide (SO_3), calcium oxide (CaO), potassium oxide (K_2O), aluminum oxide (Al_2O_3), and iron (II) oxide (FeO).

SiO_2 is a metal oxide that is also known as silica or silox. It is a type of glass. It has a very low coefficient of expansion (similar to Pyrex glass) with low thermal conductivity (insulation properties for a semiconductor). The percentages of SiO_2 obtained were 20.6% (OPC), 46.80% (FA), 50.75% (CBA, 45 μm), and 54.26% (CBA, 75 μm). In descending order, the highest SiO_2 content was CBA (75 μm), followed by CBA (45 μm), FA, and OPC. It showed that the finer the particle size of CBA, the higher will be the SiO_2 content.

Higher SiO_2 content indicates higher resistance to expansion and the best insulation properties (poor thermal conductivity). It exhibits higher thermal shock resistance which is a leading example of energy-efficient concrete and building infrastructure with lower thermal conductivity.

MgO is also known as magnesia. It is a semiconductor with a rock-salt structure that has a wide valence band (~6 eV) and a large dielectric constant (9.8) (George et al., 2021). Reactive MgO is used to solidify soil (Yi et al., 2013). MgO mineralizes carbon dioxide (CO_2) and produces the hydrated magnesium carbonate species (formation of M-S-H gel), generating higher strength, lower permeability, and finer microstructure (Wang et al., 2019). MgO is also reported to be more efficient than hydrated lime used in concrete. It can function as an activator of ground granulated blast-furnace slag and FA used in cement or concrete pastes and soft soil solidification. The percentages of MgO obtained were 2.2% (OPC), 1.15% (FA), 0.34% (CBA, 45 μm), and 0.26% (CBA, 75 μm). Although there is no significant difference between the percentages of CBA and its particle size, MgO does exist in OPC, FA, and CBA in low concentration that ranged between 0.26 and 2.2%.

SO_3 is produced from sulfur coal burned in coal-fired power plants. High SO_3 content in FA causes efflorescence (deposits of salts) in concrete (Ríos et al., 2020). SO_3 reacts with calcium hydroxide in normal concrete resulting in the cracking of the

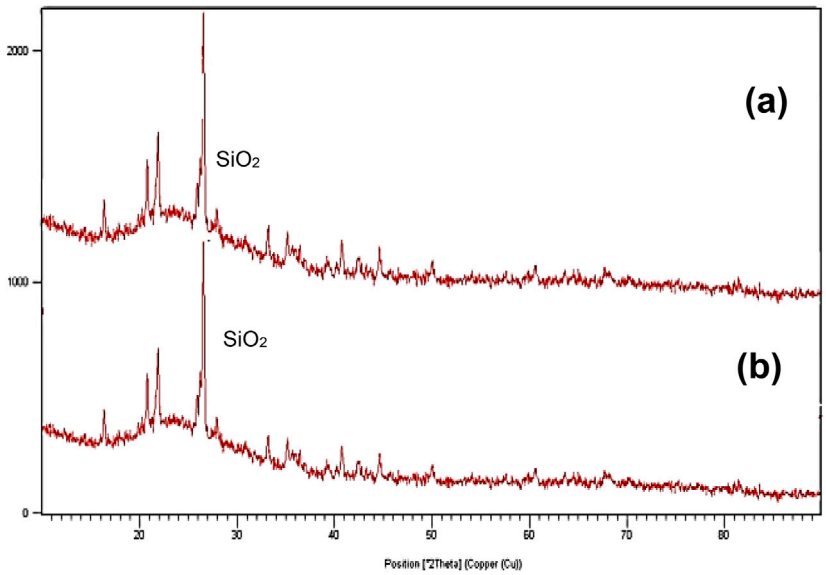

FIGURE 1 | XRD analysis for **(A)** 45 and **(B)** 75 μm of CBA.

TABLE 5 | Chemical oxide content in OPC, FA, and CBA (45 and 75 μm) and selected properties of FA (class F and class C according to ASTM 1994).

Percentage of chemical composition (%)	Chemical formula	Current research				ASTM (1994)	
		OPC	FA	BA (45 μm)	BA (75 μm)	Class F	Class C
Silicon dioxide	SiO_2	20.6	46.80	50.75	54.26	50	53
Magnesium oxide	MgO	2.2	1.15	0.34	0.26		
Sulphur trioxide	SO_3	2.7	0.53	0.75	0.62	0.4	0.1
Calcium oxide	CaO	62.9	3.32	7.37	5.53	8	0.1
Potassium oxide	K_2O	0.5	1.34	2.68	2.62	—	0.4
Aluminum oxide	Al_2O_3	4.4	18.41	17.91	17.43	20	43
Iron (II) oxide	FeO	3.3	6.08	17.94	17.00	8	0.5
ASTM classification		28.3	71.29	86.6	88.69		
Class F							
SiO_2, Al_2O_3, and $FeO_3 \geq 70\%$		-None-	Class F	Class F	Class F	—	—
Class C							
SiO_2, Al_2O_3, and $FeO_3 \geq 50\%$							
CSA A3001 cementitious materials for use in concrete		62.9	3.32	7.37	5.53		
Class F		Class CH	Class F	Class F	Class F	—	—
<8% of CaO							
Class CI							
8–20% of CaO							
Class CH							
>20% of CaO							

cement paste, affecting its durability (Mohammed et al., 2004). For this reason, the maximum SO_3 content of cement or blended cement is regulated around the world (e.g., NCh 148, ASTM C989, ASTM C150, ASTM C10, ASTM C595, and IS 3812-1981) and restricted to 5% or less. The percentages of SO_3 were 2.7% (OPC), 0.53% (FA), 0.75% (CBA, 45 μm), and 0.62% (CBA, 75 μm). The SO_3 concentration is still below the permitted limit of 5%.

CaO is also known as quicklime. It is a type of property modifier, produced by the thermal decomposition of materials (e.g., limestone or seashells) that contain calcium carbonate ($CaCO_3$). It has the ability to form solutions with silicates accelerating the phase separation of borosilicate glasses (Ahmad et al., 2019). It is also the main ingredient in OPC (Ahmad et al., 2018). The percentages of CaO were 62.9% (OPC), 3.32% (FA), 7.37% (CBA, 45 μm), and 5.53% (CBA, 75 μm).

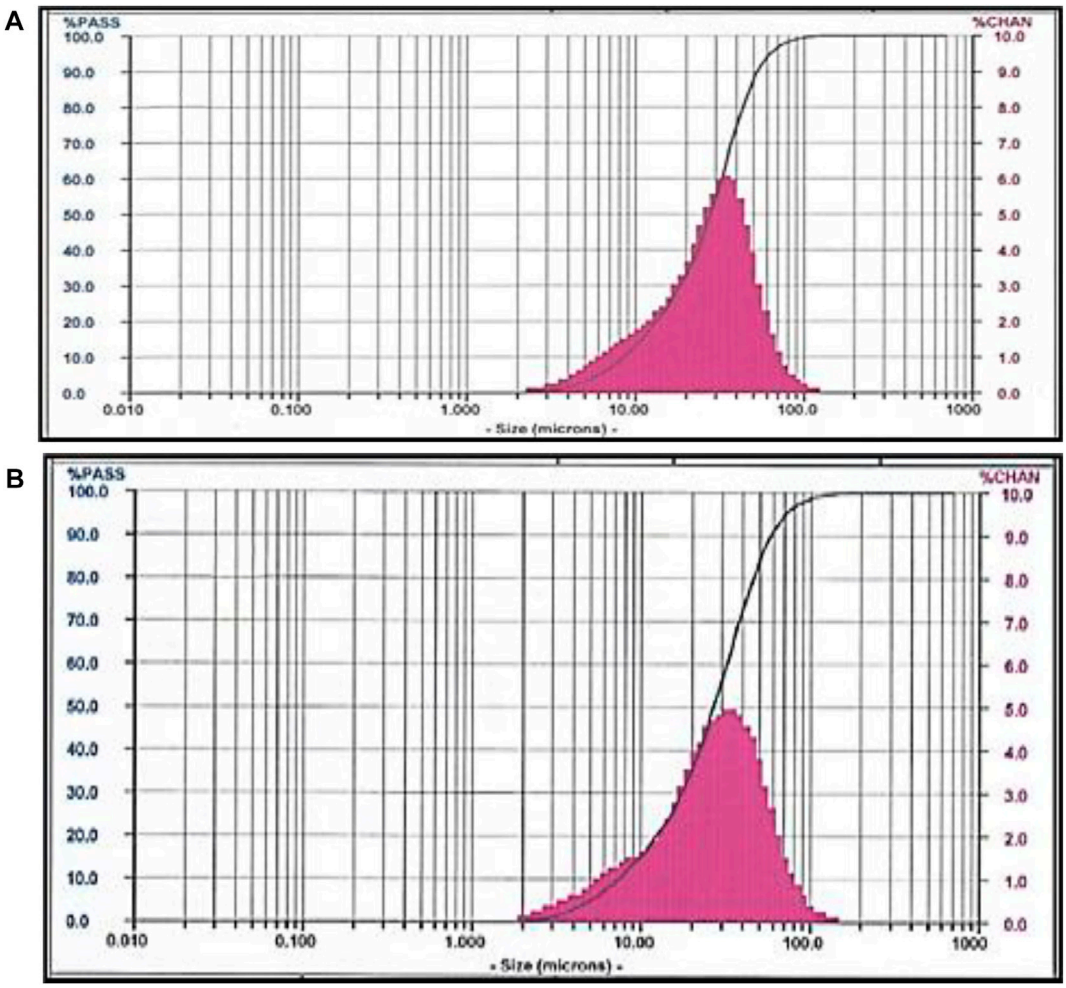

FIGURE 2 | PSD analysis for **(A)** 45 and **(B)** 75 μm of CBA.

K_2O is an alkali metal oxide containing potassium and oxygen. It provides a wide variety of binding sites and adsorbate orientations. It is important for the adsorption of sulfur dioxide (SO_2) from electricity generation. SO_2 can be reduced via oxy-coal combustion. Potassium (K) has the highest SO_3 binding strength (gaseous phase) through the formation of a sulfate (SO_4^{2-})-like molecule as compared to calcium (Ca), magnesium (Mg), and sodium (Na). K_2O present in FA in lesser amounts ranged from 0–4% (weight percentages) Galloway et al. (2015). The percentages of K_2O were 0.5% (OPC), 1.34% (FA), 2.68% (CBA, 45 μm), and 2.62% (CBA, 75 μm).

Al_2O_3 (also identified as aluminum (III) oxide) contains aluminum and oxygen. FA high in alumina content is needed to fabricate the ceramic tile (Ahmad et al., 2021a). It is an electrical insulator used as a substrate for integrated circuits (Khosla et al., 2021). The percentages of Al_2O_3 were 4.4% (OPC), 18.41% (FA), 17.91% (CBA, 45 μm), and 17.43% (CBA, 75 μm). In general, iron in coal mainly exists as pyrite (FeS_2), and less as jarosite ($KFe_3(SO_4)(OH)$ (Zeng et al., 2009) or siderite ($FeCO_3$). Coal-bound pyrite accounts for over 90% (Ruan et al., 2020). During combustion, excluded pyrite is initially decomposed to pyrrhotite (FexS) which is further melted to an iron oxy-sulfide droplet (Müller et al., 2013). Magnetite (Fe_3O_4) and hematite (Fe_2O_3) are then crystallized out successively from the aforementioned melt; while included pyrite is directly decomposed into molten FeS, subsequently, it is either oxidized into $FeO/Fe_3O_4/Fe_2O_3$ step-by-step or incorporated into glassy particles with being gradually oxidized. The percentages of FeO were 3.3% (OPC), 6.08% (FA), 17.94% (CBA, 45 μm), and 17.00% (CBA, 75 μm). Most iron-rich coals are enriched by Si + Al elements ($SiO_2 + Al_2O_3 \approx 60–70\%$) (Srinivasachar et al., 1990). The percentages of $SiO_2 + Al_2O_3$ obtained were 25.0% (OPC), 65.21% (FA), 68.66% (CBA, 45 μm), and 71.69% (CBA, 75 μm). The FA and CBA originated from iron-rich coals.

The comparison of the chemical oxide content in OPC, FA, CBA (45 and 75 μm) and selected properties of FA (Class F and Class C according to ASTM 1994) is shown in **Table 5**. Class F is classified as pozzolan while class C is cement (ASTM C618). The classification is based on the sum percentages of SiO_2, Al_2O_3, and

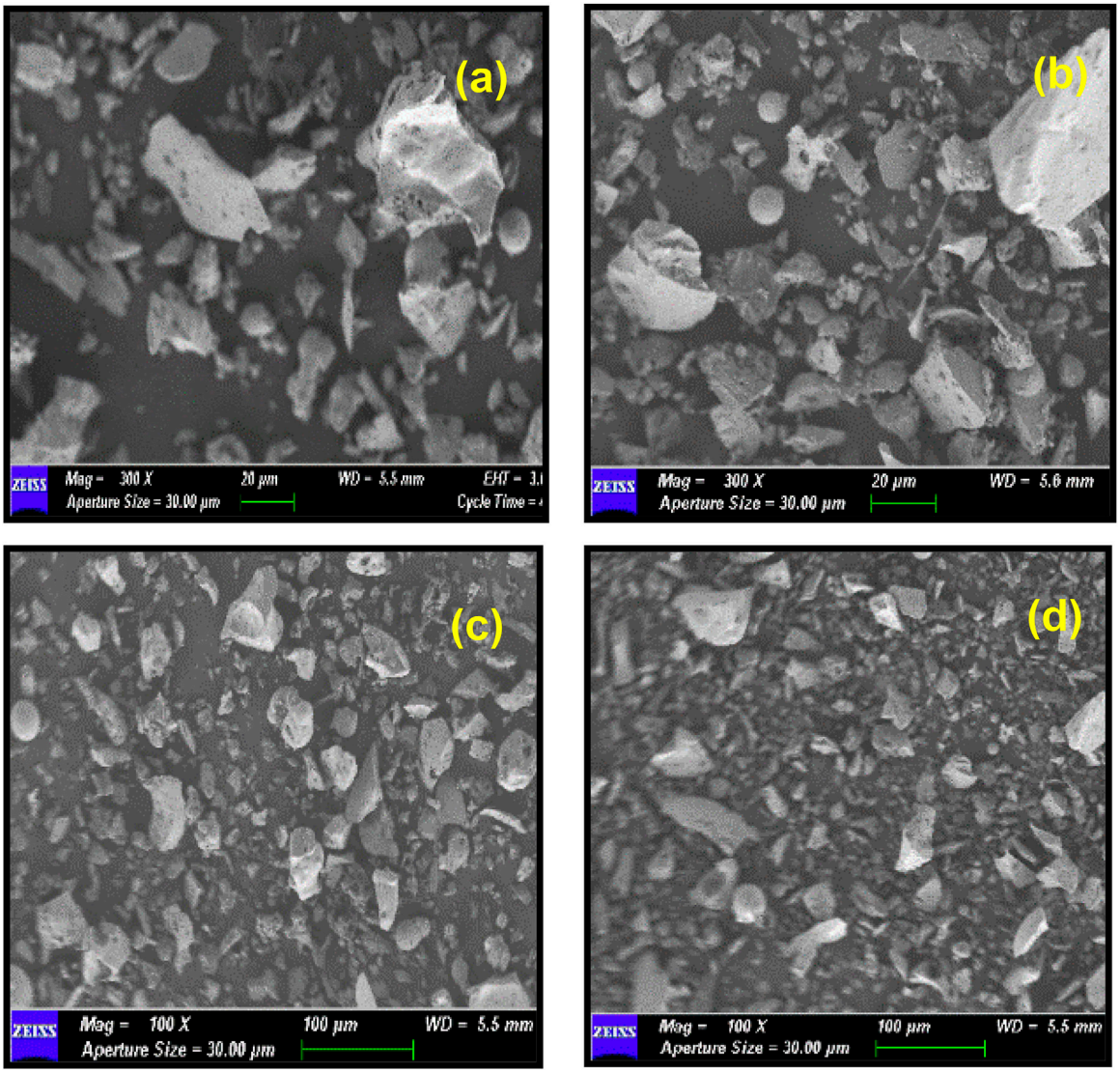

FIGURE 3 | SEM images for 45 and 75 µm of CBA under ×300 **(A,B)** and ×100 **(C,D)** magnifications.

FeO_3 (ASTM C618). The sum percentages of SiO_2, Al_2O_3, and FeO_3 equivalent to ≥70% and ≥50% can be classified as class F and class C, accordingly. The reference percentages of chemical oxides in class F were 52% (SiO_2), 0.8% (SO_3), 5% (CaO), 2% (K_2O), 23% (Al_2O_3), and 11% (FeO) (ASTM C618). The reference percentages of chemical oxides in Class C were 35% (SiO_2), 41% (SO_3), 21% (CaO), 0.7% (K_2O), 18% (Al_2O_3), and 6% (FeO) (ASTM C618). Class C contains high percentages of SO_3. The classification for OPC (28.3%) is none. The FA (71.29%) and BA (45 µm: 86.6%, and 75 µm: 88.69%) can be classified as class F. Another alternative for coal ash classification is based on the percentage of CaO content (CSA A3001 cementitious materials for use in concrete). The classifications are class F (<8% of CaO), class CI (8%–20% of CaO), and class CH (>20% of CaO) of FA. The classification for OPC (62.9%) is class CH. The FA (3.32%) and BA (45 µm: 7.37%, and 75 µm: 5.53%) can be classified as class F.

Figure 1 shows the XRD chromatogram for 1) 45 and 2) 75 µm of CBA. The 2θ scale is an angle between diffracted x-ray and an incident x-ray beam. A smooth gradual scatter indicates the fully amorphous material, while a flat and sharp peak of the graph scatters indicates a fully crystalline material.

Sen (2014) reported that the types of crystalline elements that can be detected in the cenosphere are quartz (SiO_2), rutile (TiO_2), alumina (Al_2O_3), hematite (Fe_2O_3), dipotassium oxide (K_2O), calcium oxide (CaO), sodium oxide ($N_{a2}O$), magnesium oxide (MgO), sillimanite or aluminosilicate (Al_2SiO_5), and mullite or porcelainite ($3Al_2O_32SiO_2$ or $2Al_2O_3SiO_2$). The CaO peak can be detected at 15°. The mullite can be detected at 15°, 25°, 33°, and 60°. SiO_2 can be detected at 22°, 25°, and 42°. TiO_2 can be detected at 25°.

TABLE 6 | Percentages of CBA (%), slump (mm), and types of slumps.

Types of mix	Mix Code	Percentages of CBA (%)	Slump (mm)	Degree of workability	Type of slumps
CM	CBA0	0	180	High	Collapse
Mix 75	5CBA75	5	175	High	Collapse
	10CBA75	10	165	High	Collapse
	15CBA75	15	164	High	Collapse
	20CBA75	20	155	High	Collapse
	25CBA75	25	145	High	Collapse
	30CBA75	30	120	High	Collapse
	5CBA100	5	180	High	Collapse
	10CBA100	10	164	High	Collapse
Mix 100	15CBA100	15	155	High	Collapse
	20CBA100	20	152	High	Collapse
	25CBA100	25	140	High	Collapse
	30CBA100	30	130	High	Collapse

Al_2SiO_5 can be detected at 32°, 33°, 60°, and 75°. Al_2O_3 can be detected at 33° and 35°. K_2O can be detected at 39° and 41°. CaO is marked at 39°. The Na_2O peak is at 58°. The CaO peak is at 60°. The MgO peak at 75° (Sen, 2014). Phases with the same chemical composition can have drastically different patterns. The diffraction pattern of a mixture represents a combination of scattering of each phase. The curved line at the first 30° at the 2θ position represents glass (SiO2). Crystobalite (SiO2) at 22° and quartz (SiO2) at 26° (Banerjee et al., 2008). The calcium silicate (Ca2O4Si) (Hoy et al., 2018) akermanite (Ca2Mg(Si2O7), gehlenite (Ca2Al(AlSi)O7), melilite (Ca2(Al, Mg, Fe)((Al, Si, B)SiO7), and quartz (SiO2) can be detected at 45° (Thunuguntla and Gunneswara Rao, 2018). These elements are silicates.

The observed diffraction peaks for CBA were at 15°, 21°, 22°, 27°, 28°, 33°, 35°, 36°, 41°, 43°, 45°, and 50°. The crystalline compounds observed were mullite (15°), quartz (22°, 25°, and 42°), crystobalite (22°), TiO_2 (25°), Al_2SiO_5 (33°), and Al2O3 (33° and 35°). The CBA were rich in silicates based on the highest peak at 45° indicating possible crystalline compounds such as Ca_2O_4Si, $Ca_2Mg(Si_2O_7)$, $Ca_2Al(AlSi)O_7$, $Ca_2(Al,Mg,Fe)((Al,Si,B)SiO_7)$, and quartz ($SiO_2$). Amorphous content is vital in concrete technology because it increases the material reactivation toward hydration (e.g., water retaining structure) and gives a positive effect on the strength and durability of concrete. If it is not reactive, it will act as a filler (Babat et al., 2016). The CBA samples contained both amorphous and crystalline compounds.

Figure 2 shows the PSD analysis for 45 and 75 μm of CBA. The 45 μm CBA showed a mean particle size of 27.91 μm. The finest size obtained was 8.48 μm. The coarser particle size obtained was 43.62 μm. The mean particle size of 75 μm CBA was 26.88 μm. The finest particle size obtained was 7.32 μm. The coarser particle size obtained was 58.52 μm.

By comparing the time taken for the grinding process, ranging from 15–39 min, it was shown that CBA with a grinding period of 15 min had an optimal particle size distribution, while CBA with

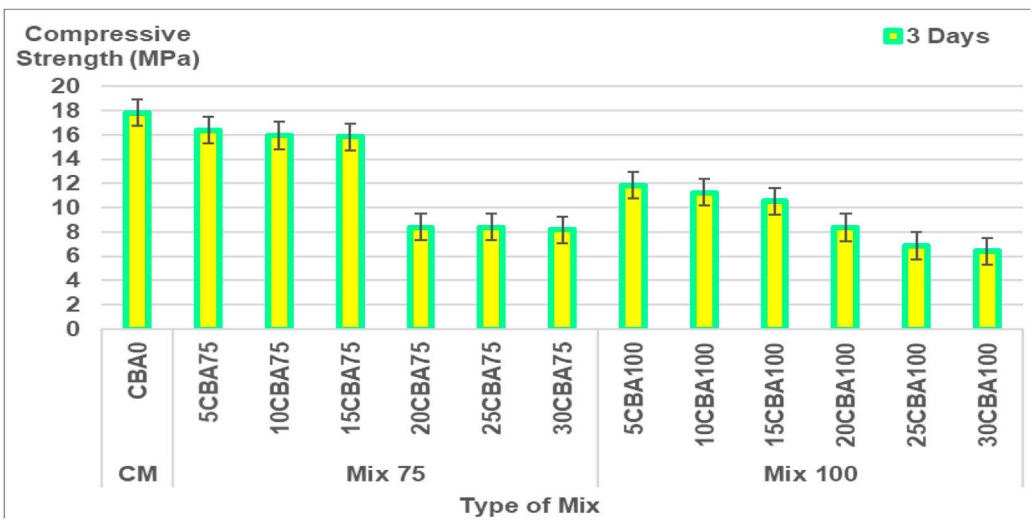

FIGURE 4 | Compressive strength (MPa) of Mix 75 and Mix 100 at 3 days.

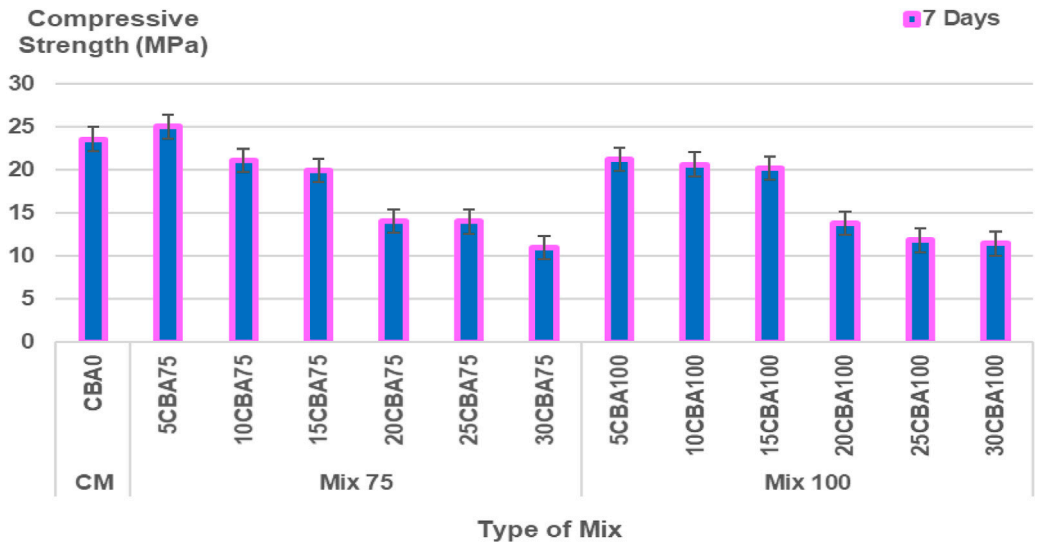

FIGURE 5 | Compressive strength (MPa) of Mix 75 and Mix 100 at 7 days.

a grinding period of more than 15 min was observed to have an even particle distribution with a sufficient number of fine particles of less than 125 μm, which had a positive impact on the concrete particle packing and on improving the concrete properties (Bajare et al., 2013). The data obtained showed a uniform particle distribution, which did not exceed the 5% average limitation established in the ASTM C618 standard. The use of a partial cement replacement material with a particle size of 14.5 μm to fill the voids between the aggregate particles can reduce the volume of the voids to be filled with cement paste, thereby reducing the volume of the cement paste needed to produce concrete (Chen et al., 2014).

The SEM images for 45 and 75 μm of CBA under ×300 and ×100 magnifications are shown in **Figure 3**. FA contains many spherical and other variant structures such as ferrospheres, cenospheres, aluminosilicate spheres, plerospheres, sub-angular minerals (quartz/feldspars), and irregular-shaped char particles (Choudhary et al., 2020). The morphological components of FA and CBA will be relatively the same. The micromorphology observation of CBA in the current research

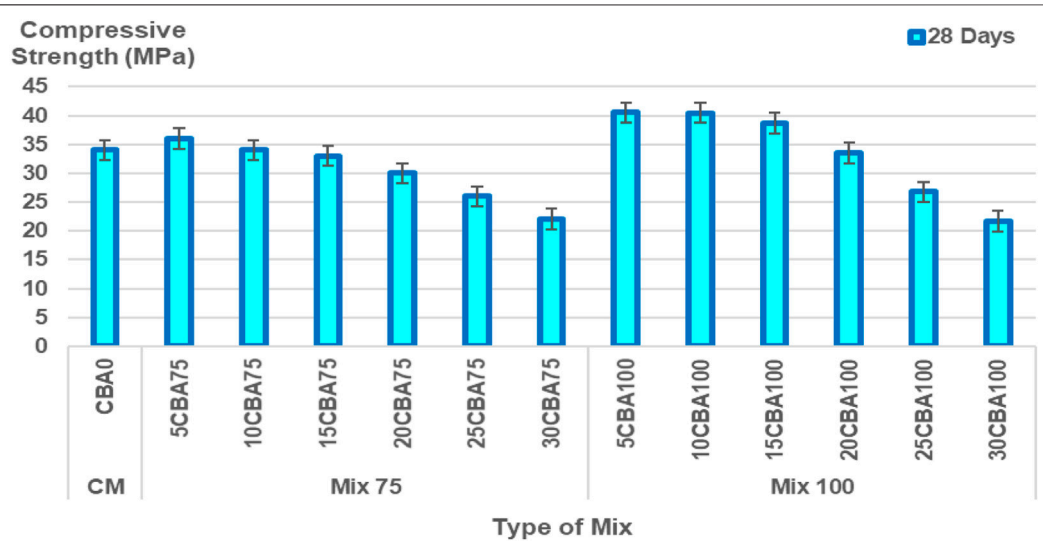

FIGURE 6 | Compressive strength (MPa) of Mix 75 and Mix 100 at 28 days.

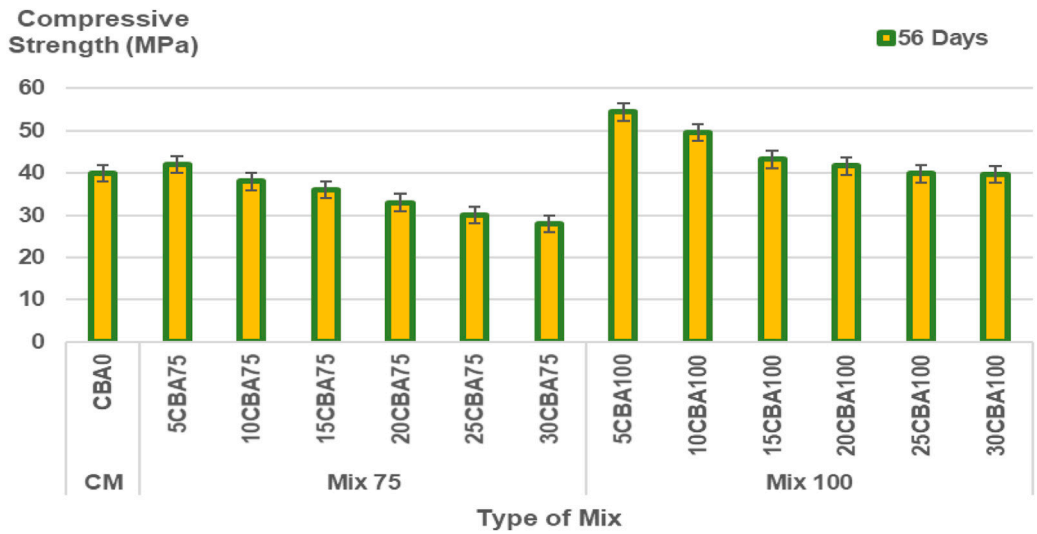

FIGURE 7 | Compressive strength (MPa) of Mix 75 and Mix 100 at 56 days.

showed that it has few cenospheres and components of irregular-shaped char particles scattered.

Effects of CBA Fineness on Concrete Workability

The workability characteristics of fresh concrete were used to determine its properties in this analysis. The percentages of CBA (%), slump (mm), and types of slumps for each mixture proportion are shown in **Table 6**. The CM (CBA0) has the highest slump equivalent to 180 mm indicating the high degree of workability. The slump type can be classified as collapse. Mixtures with a reference slump value of 180 mm were selected for this study, and the addition of CBA caused an almost 30% reduction (for 30% replacement) in slump values. The CBA naturally absorbed water in the mixture contributing to

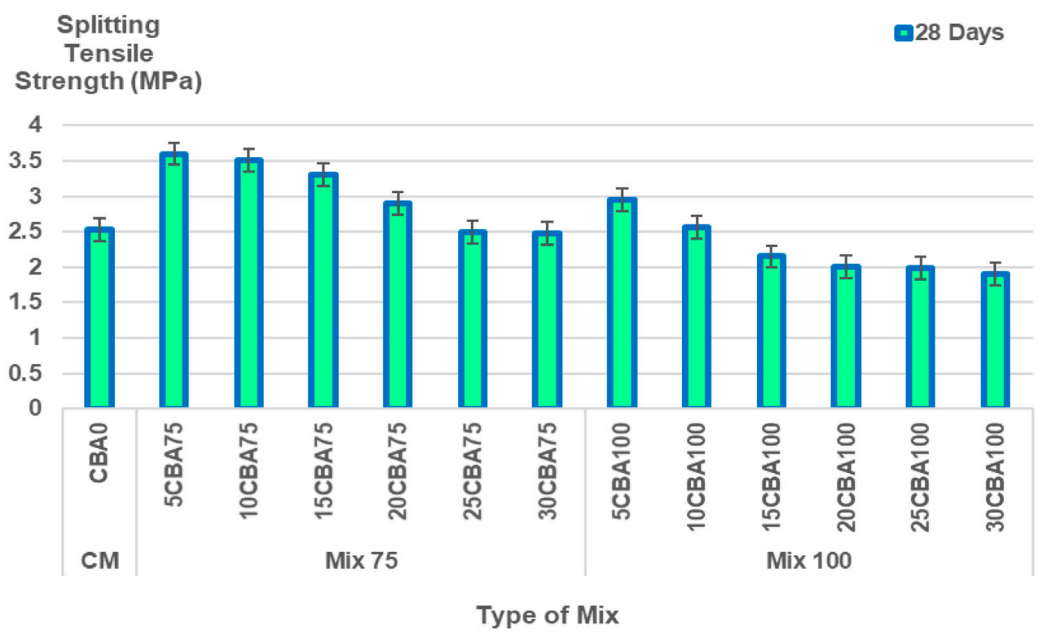

FIGURE 8 | Splitting tensile strength (MPa) of CM, Mix 75, and Mix 100 in 28 curing days.

TABLE 7 | Design layout in RSM and ANOVA for Mix 75.

Mix	Run	Process variables		Response variable
		A (curing days, day)	B (CBA, %)	Compressive strength (MPa)
	1	3 (−1)	0 (−1)	17.83
	2	56 (1)	0 (−1)	40
	3	29.5 (0)	2.8 (−1)	35.45
	4	51.0 (1)	15 (0)	35.47
	5	29.5 (0)	15 (0)	33.16
	6	29.5 (0)	15 (0)	33.16
Mix 75	7	7.9 (−1)	15 (0)	20.58
	8	29.5 (0)	15 (0)	33.16
	9	29.5 (0)	15 (0)	33.16
	10	29.5 (0)	15 (0)	33.16
	11	29.5 (0)	27.2 (1)	24.51
	12	3 (−1)	30 (1)	8.17
	13	56 (1)	30 (1)	28

TABLE 8 | ANOVA for the response surface quadratic model.

Source	SS	DF	MS	F-value	Prob > F	Indication
Mix 75	2.17	5	0.4332	90.27	<0.0001	Significant
A-curing days	1.16	1	1.16	241.30	<0.0001	Significant
B-CBA	0.3881	1	0.3881	80.87	<0.0001	Significant
AB	0.0449	1	0.0449	9.35	0.0184	Significant
A2	0.1463	1	0.1463	30.49	0.0009	Significant
B2	0.0497	1	0.0497	10.37	0.0147	Significant
Residual	0.0336	7	0.0048			
Lack of fit	0.0336	3	0.0112			
Pure error	0.0000	4	0.0000			

a higher reduction in workability and fresh mix density of concrete (Mangi et al., 2019). A superplasticizer was reported to contribute to the workability effect (Ovbeniyekede et al., 2018), similar to other porous materials such as BSA (Manan et al., 2018) and palm oil biomass clinker (Wan Ibrahim et al., 2017). The fineness of materials used as SCM or cement replacement materials is an indication of a bigger surface area for water absorption in the fresh concrete mix.

Effects of CBA Concrete Strength Improvement

The percentages of CBA (%) and comparison of compressive strength (MPa) of the mortar are shown in **Figures 5–6** and **Figure 7** for 7, 14, 28, and 56 days, respectively, and the splitting tensile strength is shown in **Figure 8**. The compressive strengths for CM (CBA0) were 14.42 ± 0.52 MPa (3 days), 20.76 ± 1.13 MPa (7 days), 23.86 ± 1.19 MPa (28 days), and 31.61 ± 1.60 MPa (56 days). The compressive strengths of CM, Mix 75, and Mix 100 were observed to increase with curing days' duration to 28 days. The strength values in 56 days have the same ranges of compressive strengths in 28 days. The compressive strength of concrete depends on the water-binder ratio, concrete age, type, and characteristics of the mix proportion. The higher percentage of water in the mix was observed to reduce the strength of concrete containing BA at early ages (below 28 days). The pozzolanic reactivity of BA particles contributes to the strength development at later ages (28 days and above). Calcium silicate hydrate (C-S-H) bond and calcium hydroxide [$Ca(OH)_2$ or free lime] will be produced upon the reaction between cement and water producing cementitious properties. As for the concrete containing

TABLE 9 | Design layout in RSM and ANOVA for Mix 100.

Mix	Run	Process variables		Response variable
		A (curing days, day)	B (CBA, %)	Compressive strength (MPa)
	1	56	0	40
	2	3	0	11.86
	3	29.5	2.8	38.23
	4	29.5	15	38.94
	5	51.0	15	42.4
	6	29.5	15	38.94
Mix 100	7	7.9	15	21.03
	8	29.5	15	38.94
	9	29.5	15	38.94
	10	29.5	15	38.94
	11	29.5	27.2	25.34
	12	56	30	39.63
	13	3	30	6.4

TABLE 10 | ANOVA for the response surface quadratic model.

Source	SS	DF	MS	F-value	Prob > F	Indication
Mix 100	3.94	5	0.7886	47.57	<0.0001	Significant
A-curing days	2.45	1	2.45	147.65	<0.0001	Significant
B-CBA	0.1733	1	0.1733	10.45	0.0144	Significant
AB	0.0923	1	0.0923	5.57	0.0504	Not significant
A2	0.23.6	1	0.2336	14.09	0.0071	Significant
B2	0.1660	1	0.1660	10.01	0.0158	Significant
Residual	0.1161	7	0.0166			
Lack of fit	0.1161	3	0.0387			
Pure error	0.0000	4	0.0000			

BA, the water will be quenched or utilized by the cement for hydration, gaining strength in the early days. Once the majority of the C-S-H gel is formed, the water then goes toward BA (Hashmi et al., 2021). This explains the slower mechanism of the improvement of strength at later ages (28 days and above) for concrete containing BA as compared to the control (concrete containing OPC).

The splitting tensile strength (MPa) in 28 days was and the splitting tensile strengths gradually decreased with an increase of CBA. The highest splitting tensile strengths were obtained with 5% CBA for Mix 75 and Mix 100 with 3.60 MPa (5CBA75), and 2.95 MPa (5CBA100) of tensile strengths, accordingly. The splitting tensile strength (MPa) of CM, Mix 75, and Mix 100 in 28 curing days is shown in **Figure 8**.

Model Optimization

The design layout in RSM and the analysis of variance (ANOVA) for Mix 75 are shown in **Tables 7**, **8** and mix 100 is shown in **Tables 9**, **10**. The two sets of 13 experimental runs in the RSM optimization, consisting of curing days (day), percentages of CBA (%), and compressive strengths (MPa) were executed using CCD. Model terms for every model Mix 75 and Mix 100 with any values of Prob > F less than 0.05 are classified as significant.

The β coefficients of actual factors for the Mix 75 quadratic model and model terms are 2.79437 (y-intercept), 0.40213A (A), −0.001253 (B), 0.000267 (AB), −0.000451 (A2), and 0.000821 (B2). Quadratic model Mix 75 and model terms A, B, AB, A2, and B2 are significant (p-value < 0.05) (**Figure 9**). The β coefficients of actual factors for the Mix 100 quadratic model and model terms for actual factors are 10.23191 (y-intercept), 1.10873 (A), 0.63574 (B), −0.010139 (A2), and −0.03115 (B2), and are shown in Fit summary in **Table 11**.

Quadratic model Mix 75 and model terms A, B, A2, and B2 are significant (p-value < 0.05) (**Figure 8**). The significant regression parameters of predictive models (Mix 75 and Mix 100) in terms of actual factors are shown in **Eqs 3**, **4**. Overall, the quadratic model is significant for optimization purpose (**Table 10**). The R2 (Mix 75: 0.9847 and Mix 100: 0.9714) represents the goodness of fit close to 1 (Ríos et al., 2020).

$$\ln \textit{Compressive Strength } (MPa) = 2.79437 + 0.40213A - 0.001253B + 0.000267AB - 0.000451A^2 - 0.000821B^2, \quad (3)$$

$$\textit{Compressive Strength } (MPa) = 10.23191 + 1.10873A + 0.63574B - 0.010139A^2 - 0.03115B^2, \quad (4)$$

where,

A = curing Days.

B = CBA (%).

The patterns of predicted versus actual values' plot and standard error designs for compressive strength are shown in **Figure 10**. The scatterplots were in a straight line showing a linear relationship and the proposed model terms were sufficient, and the constant variance assumption was verified. The standard error designs for Mix 75 and Mix 100 showed that the error is least in the middle of the contour equivalent to 0.5% compressive strength. In Mix 75, the ranges of CBA were from 10–20% and curing days from 20–40.1 days. In Mix 100, the ranges of CBA were from 10–24% CBA and curing days from 20–40.1 days.

The contour plots model Mix 75 and Mix 100 for CBA (%), curing days (day), and compressive strength (MPa) are shown in **Figure 11**. In the optimization model Mix 75, curing days equivalent to 5 and below at all ranges of CBA (0%–30%) will produce a compressive strength below 20 MPa. Curing days between 5 and 18.9 days will produce a compressive strength in a range between 20 and 30 MPa. Curing days between 18.9 and 40.1 days will produce compressive strength between 30 and 40 MPa. The highest compressive strength (40 MPa) will be obtained at 45.4 curing days with 6% of CBA.

In the optimization model Mix 100, curing days from 3–13.6 days with 0–24% CBA will produce compressive strength ranging from 10–20 MPa. Curing days from 13.6–24.2 days with 0–24% CBA will produce compressive strength ranging from 20–30 MPa. Curing days from 24.2–45.4 days with 0%–30% CBA will produce compressive strength ranged from 30 to 40 MPa. Curing days from 29.5–56 days with 0%–24% CBA will produce compressive strength ranging from 40–50 MPa. Curing days from 50.7 days with 12% CBA will produce the highest compressive strength, 50 MPa. **Table 9** shows the validation

TABLE 11 | Fit summary results for Mix 75 and Mix 100.

Response	Significant model	Std. dev.	R^2	Adj. R^2	Predicted R^2	Adeq. precision	F-value
Compressive strength (MPa)	Quadratic model Mix 75	0.0693	0.9847	0.9738	0.7754	32.1387	90.27
	Quadratic model Mix 100	0.1287	0.9714	0.9510	0.5801	23.2690	47.57

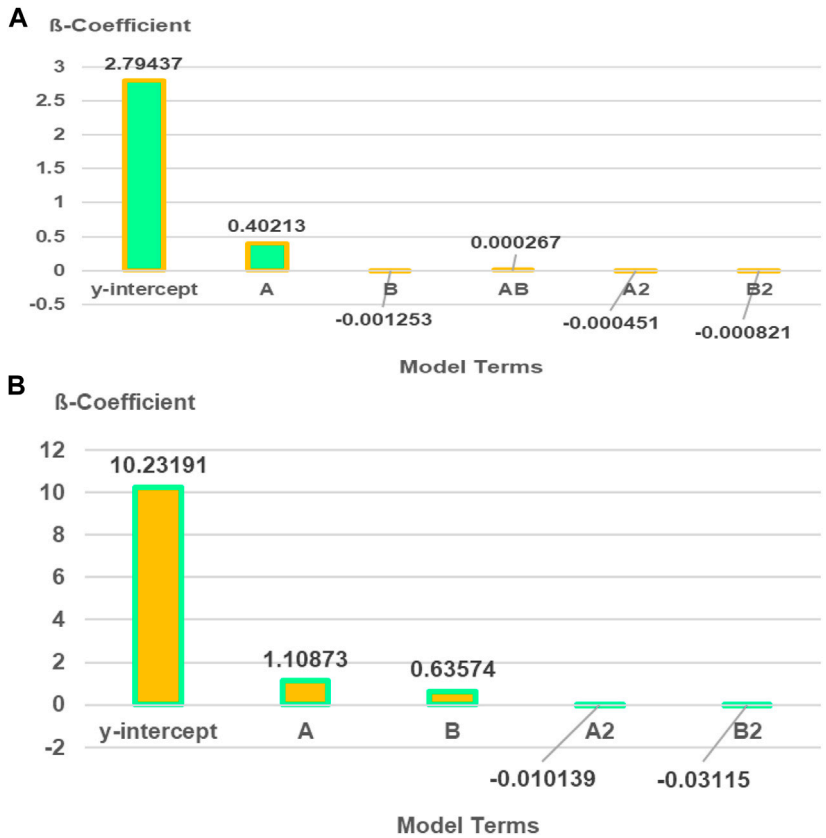

FIGURE 9 | β coefficient of actual factors for quadratic models: **(A)** Mix 75 and **(B)** Mix 100.

of the optimized model. In engineering applications, a variability of 20% of error percentage is often acceptable (Zhang et al., 2007; Baji, 2014). The period of 28 curing days was found to be the best duration for curing Mix 75 (for 5, 10, and 15% of CBA) and Mix 100 (for all percentages of CBA, 5, 10, 15, 20, 25, and 30%).

The percentages of error for Mix 75 were 3.53, 9.38, and 12.11% for 5CBA75, 10CBA75, and 15CBA75, respectively. Meanwhile, the percentages of error for Mix 100 were 11.81, 9.68, 7.35, 0.10, 11.22, and 12.43% for 5CBA100, 10CBA100, 15CBA100, 20CBA100, 25CBA100, and 30CBA100, respectively.

The period of 56 curing days was found to be the best duration for curing Mix 100 (10CBA100, 15CBA100, 20CBA100, and 25CBA100). The percentages of error for Mix 100 were 11.62, 0.34, 2.11, and 7.28% for 10CBA100, 15CBA100, 20CBA100, and 25CBA100, respectively. The compressive strengths for both Mix 75 (35 MPa, 75 μm, w/c 0.47, 15% CBA) and Mix 100 (33 MPa, 100 μm, w/c 0.47, 15% CBA) on the 28th day were comparable to compressive strengths reported by Kamal et al. (2021) (10% CBA, 75 μm, w/c 0.45: 30 MPa, 15% CBA, 100 μm, w/c 0.50: 32 MPa and Abd Manan et al. (2021b) 1% BSA, 75 μm, w/c 0.55: 28.77 ± 1.45 MPa, 2% CBA, 75 μm, w/c 0.55: 29.50 ± 1.45 MPa. However, compressive strength of high-strength concrete reported by Khongpermgoson et al. (2020) was higher, equivalent to more than 55 MPa for 0, 15, 25, and 35% CBA percentages (45 μm, w/c 0.25).

DISCUSSION

This research consisted of physicochemical properties of CBA using the technique of X-ray fluorescence (XRF), X-ray diffraction (XRD), particle size distribution (PSD), and a scanning electron microscope (SEM) and mechanical properties of the concrete strength properties (workability, compressive, and splitting tensile strengths), and optimization of concrete strength improvement using response surface methodology (RSM) has been investigated and findings are discussed. Coal bottom ash was collected from the Jimah Coal-Generated Power Plant located in Port Dickson, Negeri Sembilan Darul Khusus, Malaysia, oven-dried for 24 h, and ground and sieved to 75 and 100 μm. The XRF analysis showed the chemical oxide content in OPC, FA, and CBA (45 and 75 μm) and the selected properties of FA are shown in **Table 12**. The percentages of SiO2 obtained were 20.6% (OPC), 46.80% (FA), 50.75% (CBA, 45 μm), and 54.26% (CBA, 75 μm). It showed that the finer the particle size of CBA, the higher will be the SiO_2 content. Higher SiO_2 content indicates higher resistance

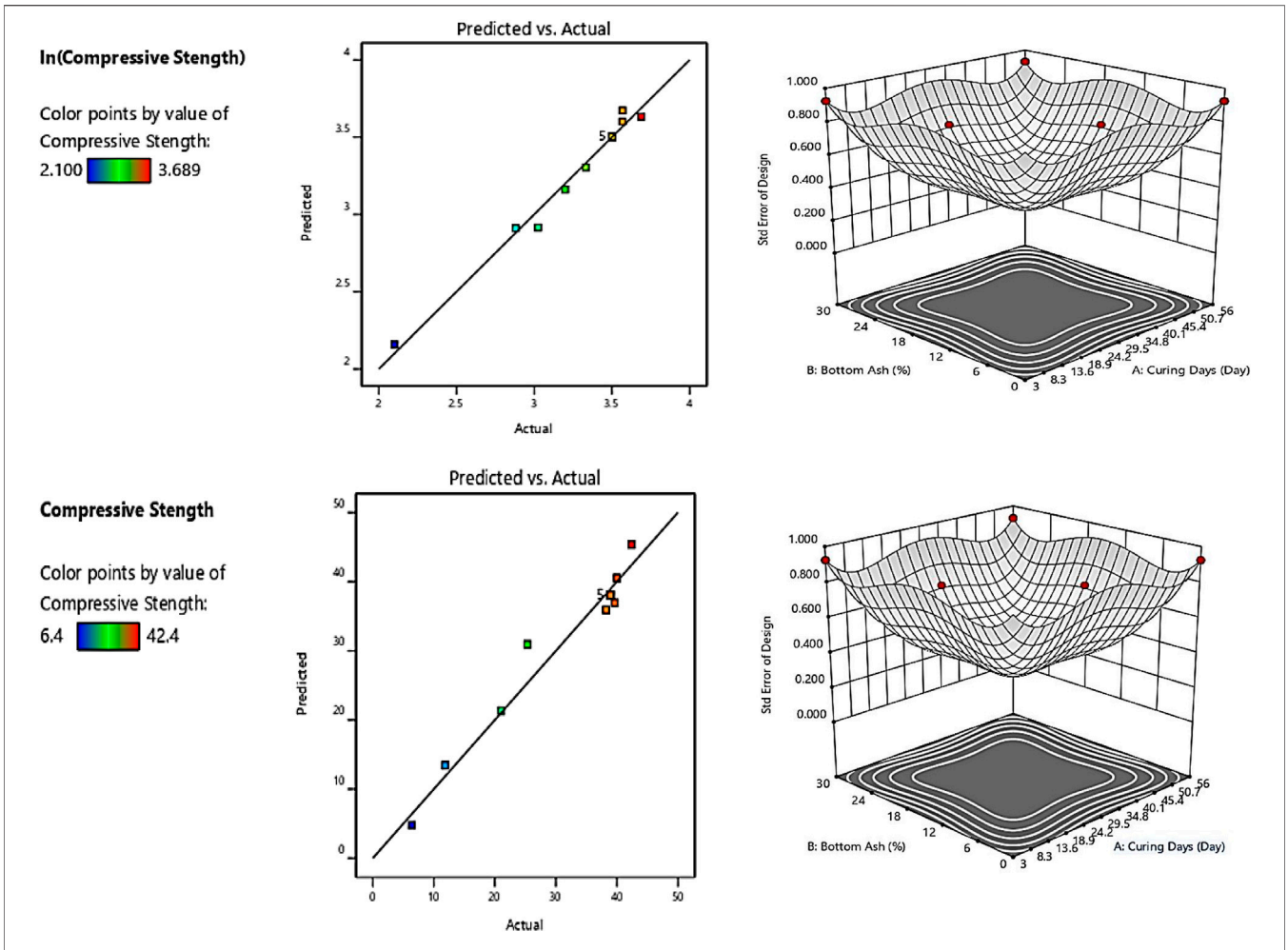

FIGURE 10 | Predicted vs. actual values' plot and standard error designs for compressive strength.

to expansion and the best insulation properties (poor thermal conductivity). It exhibits higher thermal shock resistance. SO_3 is produced from sulfur coal burned in coal-fired power plants. High SO3 content in FA causes efflorescence (deposits of salts) in concrete (Ríos et al., 2020). SO_3 reacts with calcium hydroxide in normal concrete resulting in cracking of the cement paste, affecting its durability (Mohammed et al., 2004). Fly ash is high in Al_2O_3, which contains aluminum and oxygen. The FA is high in alumina content which is needed to fabricate the ceramic tile (Ahmad et al., 2021b). It is an electrical insulator used as a substrate for integrated circuits (Khosla et al., 2021).

The SEM images for 45 and 75 μm of CBA under ×300 and ×100 magnifications found that FA contains many spherical and other variant structures such as ferrospheres, cenospheres, aluminosilicate spheres, plerospheres, sub-angular minerals (quartz/feldspars), and irregular-shaped char particles (Choudhary et al., 2020). The morphological components of FA and CBA will be relatively the same. The micromorphology observation of CBA in the current research showed that it has few cenospheres and components of irregular-shaped char particles scattered. The 45 μm CBA showed a mean particle size of 27.91 μm. The finest size obtained was 8.48 μm. The coarser particle size obtained was 43.62 μm. By comparing the time taken for the grinding process, ranging from 15–39 min, it was shown that the CBA with a grinding period of 15 min had an optimal particle size distribution, while the CBA with a grinding period of more than 15 min was observed to have an even particle distribution with a sufficient number of fine particles of less than 125 μm, which had a positive impact on the concrete particle packing and on improving the concrete properties (Bajare et al., 2013).

The workability characteristics of fresh concrete versus the percentages of CBA (%), slump (mm), and types of slumps for each mixture proportion found that CBA0 has the highest slump equivalent to 180 mm indicating a high degree of workability. The CBA naturally absorbed water in the mixture contributing to the higher reduction in workability and fresh mix density of concrete (Mangi et al., 2019). The compressive strength (MPa) of CM, Mix 75, and Mix 100 against 3, 7, 28, and 56 curing days indicated that

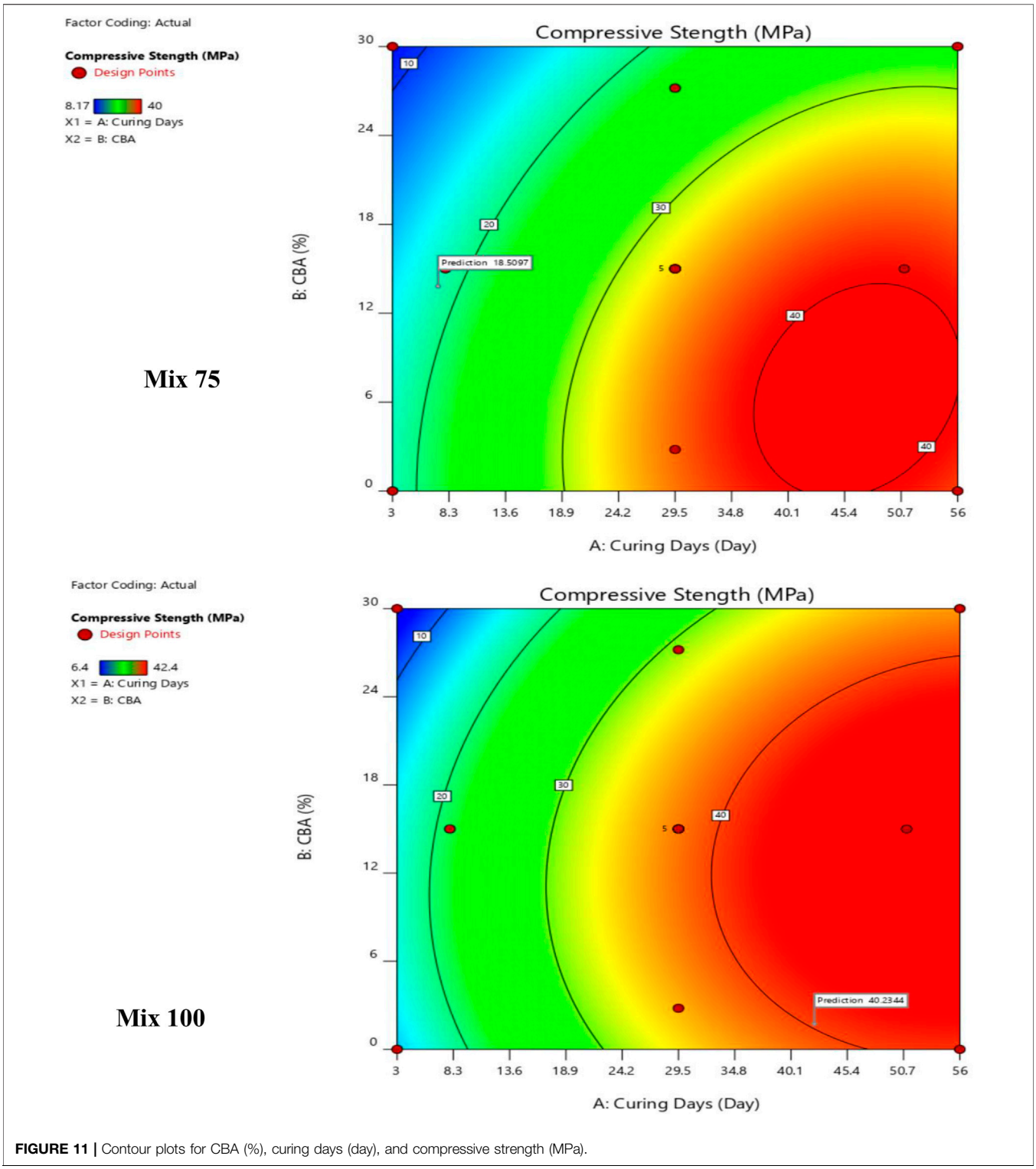

FIGURE 11 | Contour plots for CBA (%), curing days (day), and compressive strength (MPa).

compressive strength increased on the 28th day. The compressive strength of concrete depends on the water binder ratio, concrete age, type, and characteristics of the mix proportion. The pozzolanic reactivity of BA particles contributes to the strength development at later ages (28 days and above). Once the majority of the C-S-H gel is formed, the water then goes toward BA (Hashmi et al., 2021). This explains the slower mechanism of the improvement of strength at later ages

TABLE 12 | Validation of the optimized model.

Curing days	3 days		Percentage error	7 days		Percentage error	28 days		Percentage error	56 days		Percentage error
Code	Experimental	Predicted		Experimental	Predicted		Experimental	Predicted		Experimental	Predicted	
5CBA75	16.40	10.80	34.13	25.00	15.14	57.48	36.00	37.27	3.53	42.00	65.10	55.01
10CBA75	15.94	10.63	33.32	21.12	14.98	51.02	34.00	37.19	9.38	38.00	65.12	71.38
15CBA75	15.84	10.34	34.70	19.97	14.71	50.19	33.00	37.00	12.11	36.00	65.03	80.64
20CBA75	8.41	9.95	18.28	14.07	14.33	32.92	30.00	36.69	22.30	33.00	64.83	96.44
25CBA75	8.39	9.44	12.50	14.00	13.83	37.01	26.00	36.27	39.51	30.00	64.51	115.03
30CBA75	8.17	8.82	7.94	11.00	13.23	44.24	22.00	35.74	62.47	28.00	64.08	128.87
5CBA100	11.86	15.87	33.78	21.22	19.90	21.26	40.51	35.73	11.81	54.43	42.92	21.14
10CBA100	11.25	16.71	48.53	20.63	20.74	22.47	40.49	36.57	9.68	49.52	43.77	11.62
15CBA100	10.52	15.99	52.04	20.17	20.02	31.97	38.70	35.85	7.35	43.20	43.05	0.34
20CBA100	8.38	13.72	63.74	13.78	17.75	28.22	33.55	33.58	0.10	41.66	40.78	2.11
25CBA100	6.86	9.89	44.19	11.82	13.92	61.89	26.75	29.75	11.22	39.85	36.95	7.28
30CBA100	6.40	4.50	29.62	11.46	8.53	100.00	21.67	24.36	12.43	39.63	31.56	20.36

(28 days and above) for concrete containing BA as compared to the control (concrete containing OPC). Response surface methodology (RSM) analysis of variance (ANOVA) for Mix 75 and Mix 100 indicating that model terms for every model Mix 75 and Mix 100 with any values of Prob > F less than 0.05 are classified as significant. The significant regression parameters of predictive models (Mix 75 and Mix 100) show that overall, the quadratic model is significant for optimization purpose. The established model for strength enhancement of concrete using CBA was statistically significant and showed that it adequately represented the design space. The established model can significantly assist in the application of CBA in construction industries.

CONCLUSION

This research consisted of the physicochemical properties of CBA (XRF, XRD, PSD, and SEM) and the strength properties (workability, compressive, and splitting tensile strengths) and optimization of concrete strength improvement using RSM. The particle size of CBA displayed significant effects on the concrete engineering properties and volume of CBA applied in the concrete. The slump type for Mix 75 and Mix 100 was classified as the collapse type. Although the workability of Mix 75 and Mix 100 was reduced with the addition of CBA, the degree of workability for both mixes was classified as high and suitable for sections with congested reinforcement.

Based on the ASTM 1994 classification, the FA (71.29%) and BA (45 μm: 86.6%, and 75 μm: 88.69%) can be classified as class F. CSA A3001 classification for OPC (62.9%) is class CH. FA (3.32%) and CBA (45 μm: 7.37%, and 75 μm: 5.53%) can be classified as class F. CBA was rich in silicates based on the highest peak at 45° indicating possible crystalline compounds observed on 45 and 75 μm CBA. The mean particle sizes of 45 and 75 μm CBA were 27.91 and 26.88 μm, respectively. The SEM images for 45 and 75 μm of CBA under ×300 and ×100 magnifications showed that CBA has few cenospheres and components of irregular-shaped char particles scattered.

The compressive strength of concrete increased with the number of curing days. The optimal percentage of CBA in Mix 75 is equivalent to 6% within 45 curing days producing 40 MPa of compressive strength. Meanwhile, the optimal percentage of CBA in Mix 100 is equivalent to 12% within 51 curing days producing 50 MPa of compressive strength. Based on the validation of the optimized model, the period of 28 curing days was found to be the best duration for curing Mix 75 (for 5, 10, and 15% of CBA) and Mix 100 (for all percentages of CBA, 5, 10, 15, 20, 25, and 30%). The period of 56 curing days was found to be the best duration for curing of Mix 100 (10, 15, 20, and 25% of CBA). The established model for strength enhancement of concrete using CBA was statistically significant and showed that it adequately represented the design space. The established model can significantly assist in the application of CBA in construction industries.

The limitation of the present study is the regulation by the Malaysian government in permitting the use of CBA in the construction industry. The future work needed to extend the experimental observations is the cost-benefit analysis and estimation of greenhouse effect reduction on the usage of CBA in the concrete.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Conceptualization, SB; Methodology, FMN, NLMK, and software, TSBAM validation, ZI formal analysis, DM; investigation, NLMK writing—original draft preparation, SB. TSBAM, project administration, SB; funding acquisition, SB and ZI formating and editing: MA.

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Green Energy Consumption and Inclusive Growth: A Comprehensive Analysis of Multi-Country Study

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Whenever there is a question of environmental quality and inclusive economic growth, green and renewable energy consumption leads the debate. This paper explores the relationship between green energy consumption and inclusive economic growth. It employs GMM panel data modelling frameworks for understanding the "green energy vis-à-vis -growth paradox". It uses post-COVID-19 data for eighty-three countries between 2010 and 2020. These countries are divided into high-, middle- and low-income as per the World Bank's classifications. The selected composite variables are consisting of GDP growth, poverty, income equality and employment measures. The study reports that green energy positively contributes to inclusive growth despite its lower contribution to overall energy usage in low-income countries. It observes that socio-digital inclusion and green energy together impact positively on inclusive growth in all income groups (low, middle and high). This means citizens of the selected countries are aware of the pros and cons of green energy that helps countries to mitigate the negative impacts of countries' transition to clean energy usage in terms of job losses, higher costs of clean energy and uncertainty to energy supply. Furthermore, results also reveal that green energy is significant contributor towards achieving inclusive growth, however it his highly significant in high income countries compared to other groups, showing its higher use in it. This comprehensive study is the first of its kind providing comparative analysis of 83 countries which explores and compares the interesting impacts of green energy consumption on inclusive growth in global data from the designated income groups.

Keywords: green energy, inclusive growth, socio-digital inclusion, global data, institutions

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INTRODUCTION

Global catastrophes in economic terms can follow a long period of global prosperity, and it has been the subject of much debate due to Gilmore., (1976), Jackson., (2009), Kaufmann et al., (2002) among others (Segerstrom., 1998; Young., 1998). The great ambition today for economic growth is that it should be inclusive (Aslam et al., 2021; Fay., 2012; Koirala., 2019; Kouton., 2021; Montmasson-Clair and das Nair, 2017; Zulfiqar et al., 2016). In a real-world analysis, the growth determinants follow time varying-patterns and are asymmetric in nature (Ling et al., 2022). The debate on inclusive growth was triggered by the World Bank and its partners for a focus on sustainability of inclusive growth, particularly in the late 2000's. The drive for sustainable economic growth is occurring at the same time as demands for better standards of living, and an issue of poverty reduction in many developing countries (Midilli et al., 2006; Jackson., 2009; Fay., 2012; Yip et al., 2016; Romano et al.,

2017; Alola et al., 2021; Sachs, et al., 2021a; Dantas et al., 2021; Kirikkaleli and Adebayo., 2021; Nundy et al., 2021; Sachs et al., 2021; Ge et al., 2022). However, despite much research on achieving sustainable inclusive growth, many countries still suffer from high-income inequalities, widespread poverty, and high unemployment levels, which is not measured while taking care of economic growth measures such GDP alone (Nguyen, 2021a; Roberts et al., 2021; Hassan et al., 2022; Inam and Murat., 2022). Government policymakers continue to devise regulations that may address the effects of this crisis, but have never been completely successful, so many countries are diverging rather than converging in their economic progress (Zulfiqar et al., 2017). Today economists are talking about inclusive growth; a type of growth that is focused on advances for all in society (Ali and Son., 2007; Ranieri and Ramos., 2013; Montmasson-Clair and das Nair., 2017; Ngepah., 2017; Aslam et al., 2021).

More than 200 million people worldwide are unemployed, and more than 15 million people in OECD countries are more unemployed today than when the GFC (Global Financial Crisis) began in 2007 (Martin., 2009). This level will reach 205 million people unemployed throughout the world in 2022 (Liu and Feng., 2022). Similarly, millions of people in developing countries remain poor and are unable to have three meals a day (Sewpaul., 2005). The risk of deep unemployment is leading to an emergency that exacerbates poverty and inequality to alarming levels. Economic downturns in developing and underdeveloped nations have a direct bearing on weak institutional structures in the face of already high levels of poverty, unemployment and under-employment (Williamson., 1998; Aghion et al., 2004; Tabellini., 2008; Siddiqui and Ahmed., 2013; Aslam and Farooq., 2019; Aslam., 2020). People in developing and underdeveloped countries are raising their concerns and demands: the right to earn, eat and have a respectful life, which is threatened by high levels of poverty and little new job creation (Reutlinger., 1984; Chowdhury., 2000; Fortman., 2006; Fujiwara., 2006; Ismael., 2006; Shah and Das., 2007; Tiwari., 2007; Nunan and Devas., 2014). Asia follows Africa in terms of high inflation rates and life becoming difficult, particularly in the wake of COVID-19 (Alzúa and Gosis., 2020; Atılgan., 2020; Cottani., 2020; Deyshappriya., 2020; Murphy et al., 2020; Tinson., 2020; Sachs., et al., 2021a; Bargain and Aminjonov., 2021; Cooney and Shaefer., 2021; Erdoğdu and Öz, 2021; Ghouse et al., 2021; Nundy et al., 2021; Rodriguez and Atamanov., 2021; Yeganeh., 2021).

Further growing pressure on international organizations to devise a policy that targets sustainable development has further strengthened the argument on the need for inclusive growth, rather than economic growth alone (Sachs, et al., 2021a; Sachs, et al., 2021). This led to the revolutionary transfer of the interests of economists to the new global economic debate of inclusive growth, which is in line with the international commitment to the UN's Sustainability Development Goals (SDGs). More specifically, in the early 2000's, a policy framework for improving the lives of the poor in society was developed and specially to improve service delivery so that they can also benefit from the fruits of economic growth, particularly where institutional systems are weak and technological development is slow.

Advances in technology for making economic growth possible depend on energy use (Dresselhaus and Thomas., 2001; Stiegel and Maxwell., 2001; Sohag et al., 2015; Yip et al., 2016; Thomas et al., 2017; Wang et al., 2017; Santosh et al., 2019; Yüksel et al., 2020; Alola et al., 2021; Mohideen., 2021). The more a country is technologically advanced, the more energy that will be used. Moreover, modern technology incorporates digital and social inclusion that should create more awareness in people about the use of green energy rather than energy such as fossil fuels which harm the environment (Lund., 1999; Midilli et al., 2006; Fay., 2012; Hartmann and Apaolaza-Ibáñez., 2012; Karatayev and Clarke., 2016; Bhowmik et al., 2017; Gibson et al., 2017; Oncel., 2017; Riahi et al., 2017; Romano et al., 2017; Sangroya and Nayak., 2017; Wackernagel et al., 2017; Carfora et al., 2018; Wang et al., 2018; Hewitt et al., 2019; Koirala, 2019; Stjepanović et al., 2019; Chien et al., 2021). The countries that are more technologically advanced are now more sensitive to environmental degradation and choose to invest in renewable energy options (Al Irsyad et al., 2017; Wackernagel et al., 2017; Stadler et al., 2018; Hewitt et al., 2019; Ayobamiji et al., 2022; Chen et al., 2022). Inclusive growth is encouraged through green energy, creating more and different employment opportunities and also saving the environment. Here, it is important to consider how socio-digital inclusion creates awareness among people, while also opening up productive employment opportunities for poor people seeking work (Helsper, 2017; Aslam et al., 2019; Helsper, 2019; Nundy et al., 2021). We thus claim that socio-digital inclusion and green energy go hand-in-hand to achieve the broader target of inclusive growth. Inclusive growth in broader terms generates equitable employment opportunities for all, while removing great swathes of poverty as much as possible (Ali and Son., 2007; Aslam and Farooq., 2019; Aslam et al., 2021; Kouton., 2021; Montmasson-Clair and das Nair., 2017).

It has been observed that literature is more focused on economic growth rather than taking care of the poor. However, when the resources are limited, it becomes difficult for a country to become more technologically advanced and its people suffer from poverty, income inequalities and high unemployment, and usually coupled with high inflation rates (Aslam and Farooq., 2019). It is now imperative to find solutions that promote inclusive economic growth to reduce the gap between rich and poor - not just in the terms of income inequalities, but also in terms political, social and other living standards. Doing so requires dramatic and solution-oriented research, which is clear, and focused on generating productive employment opportunities so that the fruits of growth are shared equally within society. We add to the existing literature by addressing four major research questions (RQ): 1) Can green energy promote inclusive growth and how does it change in different income worlds?; 2) Can social and digital inclusion, in the presence of green energy, change the different income worlds?; 3) Given that COVID-19 has triggered much economic misery throughout the world, especially for the poor and middle class, do society's institutions function to make inclusive growth possible in the different income worlds?; and 4) Does social and digital inclusion interact with green energy to

achieve inclusive growth and does it vary in the different income groups? The results from this study reveal that green energy is significant contributor towards achieving inclusive growth, however it his highly significant in high income countries, showing its higher use in it.

LITERATURE REVIEW

The relationship between institutional quality, income inequalities, energy use, and economic growth has been around for a long time in academia, and much debated in public or government policy (Aslam., 2020; Aslam et al., 2021; Sareen., 2021; Stiegel and Maxwell., 2001; Thomas et al., 2017; Yip et al., 2016; Zulfiqar et al., 2016, 2017; Kirikkaleli, D., et al., 2022). However, most of the literature has not tackled the theme of energy use, particularly green energy and its impact on inclusive growth (Mohsin et al., 2021). Not much has been done on examining the impacts on different income groups. Earlier research analyzed institutional impacts, energy, social and digital connectivity on economic growth, but did not compare world-level data. The emergence of new institutional economics in the 1990's, produced strong evidence on the role of institutions in economic growth, which was overlooked previously (North., 1989; North., 1991; Collard., 1995). This also gave a new dimension to studies that were broader in their perspective, i.e., assessing the determinants of inclusive growth rather than economic growth alone.

In one such study, Aslam and Farooq., 2019 look at the determinants of inclusive growth in selected Asian countries divided into two main categories–middle- and low-income countries. The study supports those institutions can play a significant role in achieving inclusive growth. However, this study is limited in terms of selected countries, ignores high income countries, and also does not cater for the effects of endogeneity. In their work, Aslam and Zulfiqar et al., 2016 explore the determinants of inclusive growth and forecast the future impacts of different policy variables on achieving it. However, their research is limited in terms of chosen countries and ignored developed countries. Zulfiqar et al., 2016 investigate the links between financial inclusion and its impact on inclusive growth in Pakistan. The study reveals interesting results but is again limited to Pakistan only and does not cater for the effects of endogeneity. The study also overlooks the impacts of institutions on inclusive growth. Another study by Aslam et al., 2019 looks for the possible contributors to inclusive growth by examining the role of social and digital inclusion in world-level data. These authors used a cross-panel lagged model (CPLM) and ignored major determinants of inclusive growth such as energy use, inflation, trade openness, institutions and investment. Similarly, Aslam et al., 2021 used world-level data and drew interesting insights while looking at how social and digital inclusion can play a role in inclusive growth in different income countries. The study though comprehensive lacks any assessment of the impact of green energy use on inclusive growth.

Much of the literature on the other hand, is focused on how social inclusion, digital inclusion, institutions and green energy

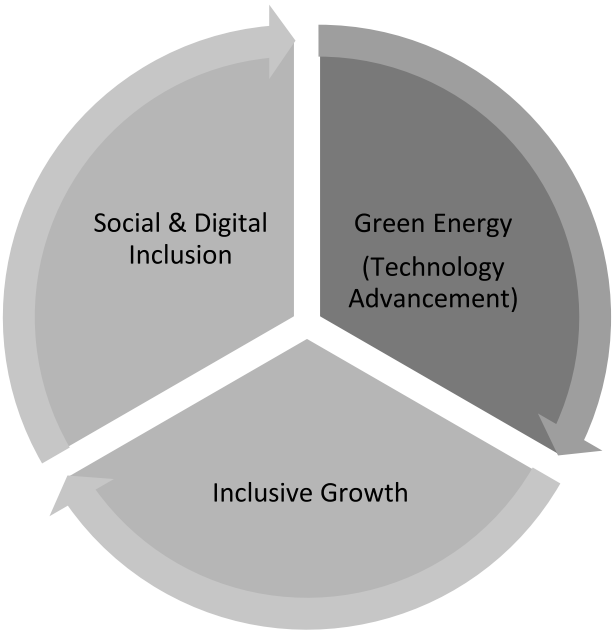

FIGURE 1 | Radial diagram of key linkages.

can shape economic growth in separate models using selected countries only (Lund., 1999; Bailey., 2005; Olphert et al., 2005; Midilli et al., 2006; Hospes and Clancy., 2011; Hartmann and Apaolaza-Ibáñez., 2012; Giambona and Vassallo, 2014; Karatayev and Clarke., 2016; Arcidiacono et al., 2017; Bhowmik et al., 2017; Gibson et al., 2017; Oncel., 2017; Riahi et al., 2017; Romano et al., 2017; Sangroya and Nayak., 2017; Thomas et al., 2017; Carfora et al., 2018; Wang et al., 2018; Sareen., 2021). Barely any significant study is carried out at the world level in three different incomes groups and creates meaningful policy options for inclusive as well as economic growth. A study in point is that by Aslam., (2020), which looks for the impact of human capital on economic growth but ignoring inclusive. Similarly, a study by Farooq et al., (2019) looks at the triangular nexus between institutions, trade openness and agriculture growth, but not how these can achieve inclusive growth. Similarly, Qamar et al., 2020 look at the effects of institutions on economic growth, rather inclusive growth.

A study by Kouton., 2021 assesses the role of energy use on inclusive growth but is limited to African countries. Such a study may be helpful but can bring more fruitful results if using a continental comparison. Such a study is very insightful and has explored the impact of energy on inclusive growth. However, the study is lacking in two respects; 1) the study is limited to only African countries; and 2) green energy and not energy is more desirable for targeting sustainable inclusive growth. Alola et al., 2021, Carfora et al., 2018, Dresselhaus and Thomas., 2001, Gibson et al., 2017, Hassan et al., 2022 and Sareen., (2021) all elaborated on the role of energy use in economic growth but not how energy use can lead to productive employment opportunities, curtailing poverty and reducing income gaps. The present study aims at filling in the gaps in literature in

four ways. Firstly, it analyzes the world-level data into three income categories to draw more insightful policies for less developed countries to achieve inclusive growth. Secondly, it incorporates the role of green energy in inclusive growth, which is a promising variable for promoting inclusive growth. Thirdly, the study controls for the theoretical endogeneity that is present due to inclusion of institutions, which cannot be ignored while targeting inclusive growth. Fourthly, green energy is strongly linked to social and digital changes, which are very important in achieving inclusive growth. The study incorporates all the above aspects to generate more concise policy options.

INCLUSIVE GROWTH AND GREEN ENERGY: CONCEPTUAL LINKS AND THEORETICAL FRAMEWORK

Following the seminal work by Montmasson-Clair and das Nair., 2017 and Kouton., 2021 conceptual links between green energy and inclusive growth are developed and depicted in **Figure 1**. The growing rate of digital inclusion has not only created awareness among people but also has elevated job opportunities and spurred technological advances (Selwyn, 2004; Olphert et al., 2005; Brynjolfsson and McAfee., 2011). These advances are evident in the rise of sources and processes of using green energy (Dresselhaus and Thomas, 2001; Stiegel and Maxwell, 2001; Yip et al., 2016; Santosh et al., 2019). Social inclusion is social capital and it spurs development and technological advances (embedded in green energy use), leading to more jobs and employment opportunities, less income inequalities, better economic growth, and ultimately inclusive growth (Bailey, 2005; Hospes and Clancy, 2011; Giambona and Vassallo, 2014; Arcidiacono et al., 2017; Thomas et al., 2017; Mohideen., 2021; Sareen., 2021).

According to their level of economic progress, countries will take up green energy (Midilli et al., 2006; Hospes and Clancy, 2011; Romano et al., 2017; Carfora et al., 2018; Stjepanović et al., 2019; Chien et al., 2021; Kirikkaleli and Adebayo, 2021; Mohideen., 2021). Such technical and technological changes have greatly informed people's choices and decisions, and also attributed to informal norms such as culture, habits, ethics, and beliefs etc. The informal norms, combined with formal rules shape institutions, play a key role in the economic development, rather than inclusive growth of a country (Goguen and Burstall., 1983; Hodgson., 1988, 2006; North., 1989; North., 1991; Collard, 1995; Goodin., 1996; Williamson., 1998; Tabellini., 2008; Popov and Sukharev, 2017; Farooq et al., 2019; Aslam., 2020; Qamar et al., 2020; Aslam et al., 2021). An interesting link already established in the literature is the positive role of institutions, social inclusion, and digital inclusion as far as inclusive growth is concerned (Aslam et al., 2021). However, studies are very rare on the links between inclusive growth and green energy, and hardly anything has been published on socio-digital inclusion and institutional changes. A more comprehensive picture can be drawn if such comparisons are made on world-level data of high, middle, and low-income countries.

The relationship between green energy and inclusive growth can be explained in three major aspects. *Firstly*, poor countries have limited resources and weak institutional structures or proper enforcement mechanisms (Alayli., 2005; Aslam et al., 2021). With limited resources to grow and develop, these countries have less jobs to match the needs of unchecked population growth (Bloom and Freeman., 1986). This results in high rates of unemployment. With high levels of unemployment, much of the labor force as a form of human capital is wasted, and not able to take part in any technological advancement process or strategy (Teixeira and Queirós., 2016; Imran et al., 2020; Gumede., 2021; Kirikkaleli and Adebayo., 2021). A country that lacks technological capabilities is less likely to consider switching to green energy (Dresselhaus and Thomas., 2001; Alola et al., 2021; Mohideen., 2021). Consequently, such countries do not achieve a growth that is inclusive and sustainable.

Secondly, poor countries have low levels of education and high illiteracy rates (Aslam and Farooq., 2019). Not only that, they suffer from a lack of medical and healthcare systems and facilities. Health and education are not only important for human capital but also the lack of education means that people are less included in society and less connected with each other (Aslam et al., 2017). With low levels of education and minimal social inclusion, people are unaware of the digital world (Aslam et al., 2021). So, people are less aware of environmental degradation, do not choose green energy and know little or nothing about how it can productive employment opportunities. Such countries target economic growth in obsolete was and at the cost of environmental degradation (Mishan and Mishan., 1967; Kirikkaleli and Adebayo., 2021). In this way, many developing countries are unable to achieve sustainable inclusive growth.

Thirdly, many poor countries have exclusive, authoritarian and repressive political and economic institutions (North., 1989; North., 1991; Popov and Sukharev., 2017). Institutions that function well for the good of the people are imperative for any country if it wants to achieve sustainable economic growth (Collard., 1995; Aslam et al., 2021). Weak policies embedded in weak institutional structures, often overlook the use of green energy to create employment opportunities. As a result, the developing nations remain economically and technologically poor, unable to engage in sustainable inclusive growth. Based on **Figure 2** above, we deem that if society is socially and digitally modern, it is more aware of and connected to the changes occurring in the world, and more concerned about using green energy for economic progress and inclusive growth (Kouton, 2021). To test this conjecture, we introduce two interactions: 1) social inclusion and green energy; and 2) digital inclusion and green energy.

METHODOLOGY AND MODEL SPECIFICATION

Dynamic panel econometric models are commonly used explore the relationship between the variable. In this study we employed the GMM model. Kirikkaleli, et al., (2022) has used autoregressive

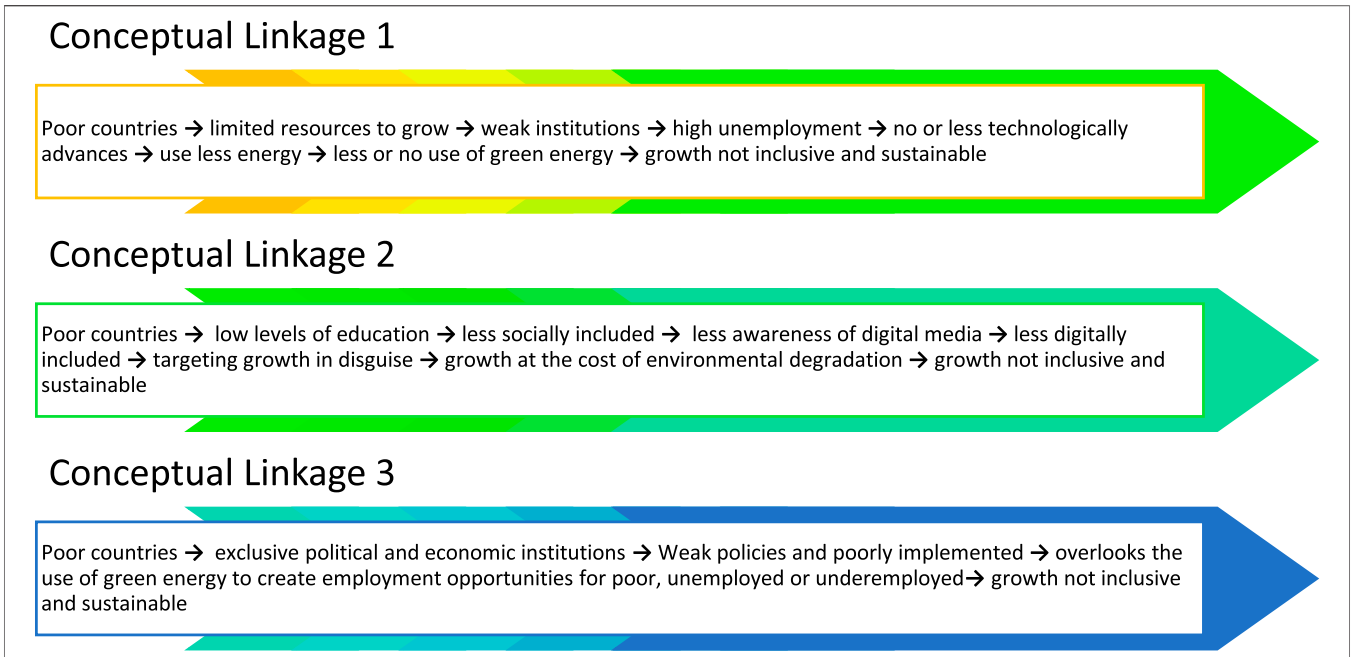

FIGURE 2 | The conceptual linkages between green energy and inclusive growth.

distributed lag (ARDL) approximations, fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS); however, all such techniques do not control for endogeneity. Moreover, the author of this paper has hardly focused on inclusive growth, which is a better measure growth that promises equity.Its general functional form is:

$$\text{Inclusive Growth} = f\,(Institutions, Social\ Inclusion, digital\ Inclusion, Green\ Energy, Trade\ Openness, Investment, Education, Inflation) \tag{1}$$

Meanwhile the econometric equation is written as follows:

$$\begin{aligned}\text{Inclusive Growth}_{it} = {} & \gamma_0 + \gamma_1 Institutions_{it} + \gamma_2 Social\ Inclusion_{it} \\ & + \gamma_3 digital\ Inclusion_{it} \\ & + \gamma_4 Green\ Energy_{it} \\ & + \gamma_5 Trade\ Openness_{it} + \gamma_6 Investment_{it} \\ & + \gamma_7 Education_{it} + \gamma_8 Inflation_{it} + v_{it}\end{aligned} \tag{2}$$

$$\begin{aligned}\text{Inclusive Growth}_{it} = {} & \gamma_0 + \gamma_1 Institutions_{it} + \gamma_2 Social\ Inclusion_{it} \\ & + \gamma_3 Social\ Inclusion_{it} {*} Green\ Energy_{it} \\ & + \gamma_4 digital\ Inclusion_{it} \\ & + \gamma_5 Green\ Energy_{it} \\ & + \gamma_6 Trade\ Openness_{it} + \gamma_7 Investment_{it} \\ & + \gamma_8 Education_{it} + \gamma_9 Inflation_{it} + v_{it}\end{aligned} \tag{3}$$

$$\begin{aligned}\text{Inclusive Growth}_{it} = {} & \gamma_0 + \gamma_1 Institutions_{it} + \gamma_2 Social\ Inclusion_{it} \\ & + \gamma_3 Social\ Inclusion_{it} \\ & + \gamma_4 digital\ Inclusion_{it} {*} Green\ Energy_{it} \\ & + \gamma_5 Green\ Energy_{it} \\ & + \gamma_6 Trade\ Openness_{it} + \gamma_7 Investment_{it} \\ & + \gamma_8 Education_{it} + \gamma_9 Inflation_{it} + v_{it}\end{aligned} \tag{4}$$

Generalized Method of Moments

The issue of endogeneity is one of the main reasons for the inconclusiveness of ordinary least squares estimates, owing to omitted variable bias (Szetela et al., 2022). To tackle the problem of endogeneity (Hansen, 1982) the GMM method can be used when data distribution is unknown. Difference GMM is an extension of the linear GMM method. The linear GMM regression equation is:

$$y_{it} = x_{it}^{'}\gamma_{0i} + v_{it} \tag{5}$$

The $t = 1, \ldots, n$, "v_{it}" is $L\ x\ 1$ denotes vector of explanatory variables. Similarly, "a_{0i}" is $L\ x\ 1$ is a vector of unknown coefficient, while" e_{it}" stands for the random error term. Endogeneity occurs when the independent variable of the equation correlates with the error term $E[v_{it}e_i] \neq 0$. In this case the ordinary least squares estimators of γ_{0i} become inconsistent and biased. Suppose we have vector of instruments z_{it} of $k{*}1$. We also have Ω_{it} matrix of time and entity varying variables $\{y_{it}, x_{it}, z_{it}\}$. The moment condition is $h_{it}\,(\Omega_{it,}\gamma_{i0}) = z_{it}, v_{it} = z_{it}\,(y_{it} - x_{it}^{'}\gamma_{0i})$. By assuming that the z_{it}

fulfills the condition of orthogonality the term is $E[h_{it}(\Omega_{it,}\gamma_{0i})] = E[z_{it}, v_{it}] = E[z_{it}(y_{it} - x_{it}^{'}\gamma_{0i})] = 0$. Conversely, $E[z_{it}, y_{it}] - E[z_{it}, x_{it}^{'}]\gamma_{0i} > \sum z_{it} y_{it} \sum z_{it} x_{it} \gamma_{0i}$, $\sum zc = E[z_{it}, y_{it}]$, and $\sum z_{it} x_{it} = E[z_{it}, x_{it}^{'}]$. The condition of rank for γ_{0i} is $\sum z_{it} x_{it} = E[z_{it}, x_{it}^{'}]$ must be full rank as $(\sum z_{it} x_{it}) = L$. This condition warrants a unique solution for $E[z_{it}(y_{it} - x_{it}^{'}\gamma_{0i})] = 0$ is γ_{0i}. The difference GMM tackles the problem of individual specific effects (fixed effect). For difference GMM **Eq. 1** can be written as:

$$y_{it} = \alpha y_{it-1} + x_{it}^{'}\gamma_{0i} + v_{it} \tag{6}$$

Where the $v_{it} = u_i + e_{it}$ and $E(u_i) = E(e_{it})$ *and* $E(u_i, e_{it}) = 0$

$$\Delta y_{it} = (\alpha - 1) y_{it-1} + x_{it}^{'}\gamma_{0i} + v_{it} \tag{7}$$

DATA

We examine the impact of green energy, institutions, and socio-digital inclusion on inclusive growth by using the panel data for eighty-three countries for the years 2010–2020. These countries are divided into high-income, middle-income and low-income places based on the World Bank's classifications. Four indices are built for social inclusion, institutions, digital inclusion and inclusive growth. The study applied the min–max normalized indexing technique to construct these indices:

1) The social inclusion index comprises eleven variables is adopted from the work by Aslam et al., 2021 and Aslam et al., 2019. Rather, this study is extension of these studies and contributes to the literature by incorporating the important variable of green energy, which the above studies overlooked.
2) Inclusive growth index is a composite of GDP growth, no poverty, income equalities and employment to population ratio. All these variables is adopted from the research by Aslam et al., 2021 and Aslam et al., 2019.
3) An institutional quality index is a composite of six institutional quality measures, "control of corruption, government effectiveness, rule of law and order, regulatory quality, voice and accountability, political stability and absence of violence" based on: Aslam., 2020; Aslam and Farooq., 2019; Aslam et al., 2021; Aslam et al., 2019; Aslam et al., 2017; Zulfiqar et al., 2016; Farooq et al., 2019; and Qamar et al., 2020.
4) The digital inclusion index includes "the number of broadband connections, internet users and the number of mobile users" is also adopted from Aslam et al., 2021 and Aslam et al., 2019.

The data on all economic variables including inflation, trade openness and investment (GFCF) are taken from the World Development Indicators (WDI), published by the World Bank. The data on institutions are acquired from the International Country Risk Guide (ICRG).

EMPIRICAL FINDINGS AND RESULTS

We found from **Table 1** that all variables greatly affect the inclusive growth for low income and middle income countries except for inflation. Inflation is prevalent in low income nations only. There were also differences in the level of significance for each variable towards inclusive growth with varying income levels. These two aspects reflect contextual differences among three income contexts. Inflation is only significant in low income places. The rationale for this is that inflation is mostly controlled in high and middle income countries because it has a stronger institutional structure than low income places (Aslam and Farooq., 2019; Aslam et al., 2021; Zulfiqar et al., 2016). Institutions on the other hand are playing a significant role in middle and high income countries but is insignificant in low income ones. These results are due to the growth of an inclusive institutional structure in the high and middle income countries

TABLE 1 | Results without interaction terms.

	High income countries	Middle income countries	Low income countries
Inclusive growth_1	0.5826*** (0.1204) [4.8361]	0.4578*** (0.1204) [3.8003]	0.3204*** (0.0674) [4.7504]
Institutions	5.3932*** (0.9314) [5.7901]	4.7752*** (0.8146) [5.8616]	0.3427 (0.9216) [0.3718]
Social inclusion	0.4920** (0.1629) [3.0186]	0.3444** (0.1529) [2.2511]	0.2411* (0.1312) [1.8364]
Digital inclusion	0.1917* (0.1101) [1.7410]	0.1242* (0.0636) [1.9502]	0.0869 (0.1476) [0.5888]
Green energy	0.6046*** (0.0765) [7.8973]	0.4232*** (0.0675) [6.2645]	0.09628* (0.0567) [1.6963]
Trade openness	0.1562*** (0.0105) [14.837]	0.2093** (0.1005) [2.0827]	0.1465** (0.0589) [2.4851]
Investment	0.6457* (0.3682) [1.7536]	0.4520* (0.2472) [1.8283]	0.3164** (0.1362) [2.3229]
Education	0.0458** (0.0173) [2.6385]	0.0321** (0.0103) [3.0951]	0.0224** (0.0097) [2.3087]
Inflation	-0.0458 (0.9745) [-0.0470]	-0.1321 (0.5367) [-0.0246]	-0.09244** (0.0457) [-2.0212]
Constant	0.2651*** (0.0198) [13.361]	0.1856** (0.0468) [3.9607]	0.1299*** (0.0111) [11.690]
Diagnostics			
Countries	29	23	28
Observations	319	253	308
Wald test (*p value*)	4,583.7*** (0.0000)	1,123.3*** (0.0000)	5,763.1*** (0.0000)
Arellano-Bond test AR (2) (*p value*)	1.4523 (0.3542)	0.9562 (0.1113)	1.5931 (0.3412)
Hansen test for instrument validity (*p value*)	2.5913 (0.4524)	3.1942 (0.1390)	1.4684 (0.1151)

Source: Estimations by the authors. *The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The values in parentheses are standard errors and the values in square brackets are the* t-*values.*

TABLE 2 | Results of social inclusion and green energy interaction.

	High income countries	Middle income countries	Low income countries
Inclusive Growth_1	0.5243*** (0.0843) [6.2179]	0.4078*** (0.1566) [2.6041]	0.4855*** (0.0738) [6.5709]
Institutions	4.8539*** (0.6520) [7.4443]	3.7752** (1.2109) [3.1177]	0.0943 (0.7712) [0.1223]
Social inclusion* green energy	0.9428*** (0.1141) [8.2634]	0.3444** (0.1118) [3.0781]	0.4100** (0.1199) [3.4176]
Digital inclusion	0.1725** (0.0771) [2.2384]	0.1342** (0.0631) [2.1245]	0.1597 (0.1105) [1.4454]
Social inclusion	0.3363** (0.1637) [2.0539]	0.4035** (0.0828) [4.8699]	0.3632*** (0.0543) [6.7974]
Green energy	0.2132*** (0.0388) [5.4929]	0.2558** (0.0604) [4.2357]	0.2302** (0.0622) [3.7021]
Trade openness	0.5441*** (0.0535) [10.153]	0.4232*** (0.0995) [4.2524]	0.5038*** (0.0539) [9.3483]
Investment	0.1406* (0.0737) [1.9074]	0.2093* (0.1069) [1.9584]	0.1302** (0.0329) [3.9461]
Education	0.5812* (0.3177) [1.8228]	0.4521* (0.2587) [1.7472]	0.5381** (0.1908) [2.8196]
Inflation	-0.00022 (0.6122) [0.0003]	-0.0321** (0.0125) [2.5513]	-0.0381** (0.0164) [3.5850]
Constant	34.122*** (4.6821) [7.2877]	28.032*** (3.2668) [8.5801]	27.038*** (3.3477) [8.0766]
Diagnostics			
Countries	29	23	28
Observations	319	253	308
Wald test (*p value*)	4,642.7*** (0.0000)	1,378.3*** (0.0000)	4,821.1*** (0.0000)
Arellano-bond test AR (2) (*p value*)	0.9836 (0.1945)	1.0547 (0.2434)	1.2395 (0.5635)
Hansen test for instrument validity (*p value*)	3.1461 (0.4524)	1.7572 (0.1390)	0.7533 (0.7532)

Source: Estimations by the authors. *The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The values in parentheses are standard errors and the values in square brackets are* t-*values.*

TABLE 3 | Results of digital inclusion and green energy interaction.

	High income countries	Middle income countries	Low income countries
Inclusive growth_1	0.5418*** (0.0768) [7.0463]	0.3691** (0.1431) [2.5798]	0.4399*** (0.0694) [6.3304]
Institutions	5.0157*** (0.5878) [8.5327]	3.3997** (1.0919) [3.1135]	0.0879 (0.0671) [0.126]
Social inclusion	0.9142** (0.4036) [2.2647]	0.3119** (0.1028) [3.0346]	0.3720** (0.1109) [3.3522]
Digital inclusion* green energy	0.1783** (0.0703) [2.5335]	0.1228** (0.0589) [2.0827]	0.1468** (0.0724) [2.0251]
Digital inclusion	0.3226** (0.1325) [2.4336]	0.1652** (0.0548) [3.0147]	0.2619** (0.0796) [3.2884]
Green energy	0.1521** (0.0655) [2.3189]	0.4086*** (0.0889) [4.5924]	0.1244*** (0.0263) [4.7144]
Trade openness	0.5623*** (0.0492) [11.421]	0.3829*** (0.0916) [4.1768]	0.4564*** (0.0515) [8.8621]
Investment	0.1453** (0.0673) [2.1577]	0.1904* (0.0983) [1.9369]	0.1201** (0.0326) [3.6757]
Education	0.6005** (0.2869) [2.0925]	0.4088* (0.2349) [1.7401]	0.4873** (0.1747) [2.7883]
Inflation	-0.0002*** (0.5519) [-0.0004]	-0.0268** (0.0134) [-2.0026]	-0.0313** (0.0125) [-2.4918]
Constant	35.259*** (4.2149) [8.3654]	25.231*** (2.9422) [8.5752]	24.337*** (3.0159) [8.0695]
Diagnostics			
Countries	29	23	28
Observations	319	253	308
Wald test (*p value*)	4,532.7*** (0.0000)	1,273.3*** (0.0000)	3,912.1*** (0.0000)
Arellano-bond test AR (2) (*p value*)	1.6745 (0.2391)	1.1531 (0.7403)	1.0674 (0.8925)
Hansen test for instrument validity (*p value*)	1.6754 (0.1004)	1.9384 (0.5446)	0.4622 (0.9457)

Source: Estimations by the authors. *The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The values in parentheses are standard errors and the values in square brackets are t-values.*

(North., 1989; North., 1991; PopovSukharev., 2017). In contrast the low income nations are mired in resistant and conservative political and economic institutions that discourage growth (Goguen and Burstall., 1983).

Green energy has a significant impact on inclusive growth in all the income groups (Kouton., 2021). However, if we chose to focus on differences, this tends to emerge and be significant in different income groups. Green energy is a highly significant contributor to inclusive growth in both middle and high income countries but not so much in the low income ones. By highlighting these differences, we can state that such results explain why the low income countries should catch up with the middle and high income countries, which have accepted the rationale for the affordability of green energy.

We now discuss results which match our perceptions of expected results for social and digital income following Aslam et al., 2021. Social inclusion may be important in all cases but is less so in low income nations (Aslam et al., 2021). Some of the underlying reasons for such differences can be summarized into two main points. Firstly, genuine differences are seen between the impact of digital inclusion on inclusive growth in three income scenarios, suggesting that digital inclusion can in the low income world achieve inclusive growth. The role of digital inclusion in inclusive growth is less noted, simply because fewer people will be connected in the online sense and so are not socially included. Secondly, low income economies have lower rates of literacy which excludes them from the drivers of growth and innovation, so they are less socially included. What results is less productive

employment opportunities leading to low or non-existent inclusive growth.

Trade openness and investment are significant contributors to sustainable inclusive growth in all income cases and there is not much variation in terms of their significance (Sohag et al., 2015; Farooq et al., 2019; Campbell and Sigalov, 2022; Ge et al., 2022). Trade creates opportunities for countries to mutually grow and benefit from the fruits of economic growth. Hence the results are according to the expectations. Similarly, investment is a promising variable that helps economic growth since it creates new avenues for employment and may also help curtail other social evils like poverty and crime.

Table 2 summarizes the arguments made in the conceptual framework about the interactions between social inclusion and green energy instruments. It shows that developing and shifting to green energy is easier when people are socially included. Such people are more aware about the changes going on in the world and the benefits of green energy. This is evident in the significant impact of interaction terms in the high, middle and lower income countries. The rest of the results do not differ much from those in **Table 1** in terms of their significance for inclusive growth. An important point to make here is that interaction of social inclusion and green energy is significant in all three income groups has the same level of significance, which strengthens their combined role in achieving inclusive growth.

While there is not much difference in the results shown in **Table 2**, **Table 3** does highlight the interactions between digital inclusion and green energy, which is an important driver of inclusive growth. The results predict no significant change in terms of other determinants of inclusive growth in the three income cases. We conclude that digital inclusion creates awareness, and a digitally included society may have the options to switch to green energy. Digital inclusion helps with inclusive growth by creating awareness and generating employment opportunities without compromising the need to save the environment and avoid pollution and degradation.

CONCLUSION

Our research suggests that switching to green energy use will help countries wanting to achieve inclusive growth. Such counterfactuals can reduce the amount of environmental degradation when new jobs are created through technological innovations in all three income level cases. We highlight how much the significance of green energy can vary due to the different income levels and conclude that it more desirable in high and middle income countries, since they have already switched to it. Low income countries, however, need to follow the processes taken up by middle and high income countries if they want a good level of inclusive growth. We can safely conclude that inclusive growth is triggered by changing to green energy. This is a novel addition to the literature, as to date, the impact of green energy use on inclusive growth at the world-level data has not been studied previously.

Our results make a case for low income countries to follow the higher and middle income nations to become more socially and digitally included. A cross-income comparison reveals that high and middle income economies are able to achieve inclusive growth due to the significant role of institutions, and digital and social inclusion. Furthermore, the introduction of control variables such as trade openness, investment and inflation lead to much less reliance on generally accepted if increasingly obsolete economic growth theories. From the perspective of our results for these three variables, they are broadly supportive of the positive role of trade openness and investment towards attaining inclusive growth.

Another interesting and novel result documented here is the interaction of social and digital inclusion with green energy. It is highly significant in achieving inclusive growth in all three income groups. This highlights that if a society is socially and digitally inclusive, it helps them to opt for green energy resources and thus further acts as a great contributor to inclusive growth. We thus conclude that unlocking the hidden potential of socio-digital inclusion can help countries mitigate the problems associated with climate change when they embrace green energy. Literature shows that many datasets used for cross-country or cross-regional analyses concerning economic development are not that comprehensive as they do not target growth for all economies. Interestingly, hardly any study has reported the impacts of green energy on inclusive growth, when taking the post-COVID-19 data into account as well. At the same time, the idiosyncratic differences between the achievement of inclusive growth through acceptance of green energy for individual countries suggests that researchers must rely on improved benchmarking of inclusive growth, so that the proceeds of trade, commerce and economic transactions help the poor.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: WDI.

AUTHOR CONTRIBUTIONS

GG worked on conceptualization and econometric analysis. AA did work on the write-up and theoretical frame framework. MB supervised the whole process and worked on data.

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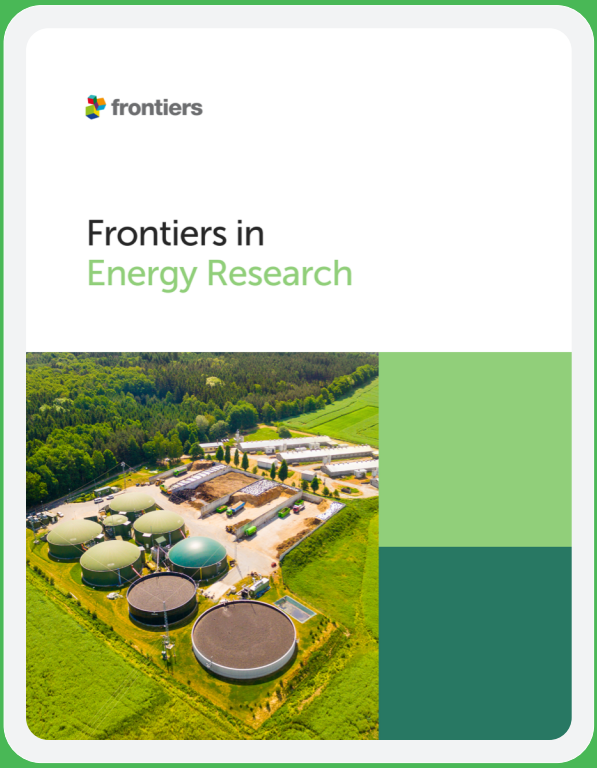

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