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Nexus Between Environmental Innovation, Energy Efficiency, and Environmental Sustainability in G7: What is the Role of Institutional Quality?

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The motivation of this study is to evaluate the role of environmental innovation, energy efficiency, and institutional quality in achieving sustainable environmental improvement in the G7 economy for the period 1980–2020. The study has implemented several econometrical tools for gauging their empirical association, including cross-sectional autoregressive distributed lag (ARDL) and directional causality with Dumitrescu-Hurlin. Study findings with cross-sectionally dependency test revealed that variables are sharing common dynamics, while the panel test of stationary documented all the variables were stationary after the first difference. Furthermore, the panel counteraction test established a long-run association among research variables. The variables coefficients with CS-ARDL revealed that renewable energy integration and environmental innovation expedite the scope of sustainability in the G7 economy in the long run. Furthermore, institutional quality assists in augmenting the process of ecological balance, that is, efficient institutional presence inductees affecting environmental policies implementation. Directional causality documented feedback hypothesis between renewable energy and environmental sustainability, environmental innovation and environmental sustainability. Moreover, the unidirectional causality was revealed between institutional quality and environmental sustainability. By considering the findings, a study has advocated that considerable time and efforts have to invest in formulating environmental policies to encourage clean energy integration for ensuring environmental quality and promoting environmental innovation.

Keywords: environmental innovation, energy efficiency, institutional quality, environmental sustainability, ARDL, CS-ARDL

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1 INTRODUCTION

Since the detrimental effects of environmental degradation have started to manifest worldwide, including climate change and global warming over time, this issue has prompted nations to seek a collective solution. The existing literature on environmental quality suggests that improving environmental quality requires two-directional courses of action: macro-fundamental contribution and energy policies based on renewable energy integration instead of fossil fuel (Cardenas et al., 2016). Clean energy integration manages the carbon emission level, enhancing environmental quality; however, Apergis et al. (2010) contented that strict energy policies harm economic growth. Therefore, the dilemma of conservative energy policy and economic growth has forced policy makers to formulate environmental policy by reconciling the environmental quality and economic growth by managing the energy integration, preferably renewable energy sources. Furthermore, another line of literature has been assessing another aspect of environmental development by exploring the role of energy efficiency and environmental innovation. Environmental degradation is a significant problem in economics and has garnered substantial attention among academicians, researchers, scientists, and economists over the last few decades. Countries are confronted with severe consequences of global warming due to the continued rise in carbon emissions and resulting perspective threats to human well-being and environmental sustainability (Lanouar et al., 2016). With the concern of environmental sustainability through reducing adverse effects due to greenhouse gas (GHG) emissions into the atmosphere, researchers have emphasized exploring the key attributes that assist in mitigating the present state of climate change (Adebayo and Kirikkaleli, 2021). During the phase of economic expansion, thorough industrialization and domestic aggregation cause substantial carbon emissions due to heavy reliance on fossil fuels rather than renewable energy; moreover, the government has neglected the ultimate consequence by focusing on economic progress only. Recently, numerous causes of environmental deterioration have been discovered, and governments are attempting to address these issues affecting environmental quality (Khan et al., 2021). CO2 emissions are thought to be a contributing cause of climate change and global warming. Environmental security has always been critical for G7, influencing agricultural production and the daily lives of millions of people (Andriamahery and Qamruzzaman, 2022a).

This study considered environmental innovation, energy efficiency, and institutional quality in environmental sustainability assessment. According to the existing literature, the impact of explanatory variables has diversified effects that can be accounted for, such as reducing ecological imbalance by lowering carbon emission, aggregated output augmentation, and economic growth. Furthermore, acceleration of technological innovation in environmental development has emphasized incremental and radical changes in technological advancement in environmental and climate changes and diffusion and adaption in industrial growth. Environmentally inventive activity is at the heart of the regulatory–adoption relationship. The fear of more regulation is likely reflected in increased innovation. Innovative activity, in turn, results in greater standardization (Carrión-Flores and Innes, 2010) and is very certainly linked with businesses' adoption of already-existing environmental technology (Popp et al., 2010). Increased regulatory rigor facilitates the adoption of the most sophisticated technologies (Popp et al., 2010), allowing for greater standardization. For institutional quality, economists, scientists, and politicians have placed a premium on institutional quality in the environmental context in recent years. Indeed, the government has the potential to influence both the direct and indirect qualities of the environment. Among the several governance features, one of the most widely regarded is the rule of law, which indicates a viable and well-functioning constitutional system. Additionally, a strong rule of law helps reduce the consequences of market failures. Additionally, Bernauer and Koubi (2009) said that competent and unbiased government institutions might be critical in fostering constructive cooperation among market actors. Consequently, the rule of law becomes critical in resolving environmental issues. Consequently, strict enforcement of carbon dioxide (CO2) control measures is essential, and firms will not hesitate to comply. On the contrary, if institutional quality issues exist, businesses would quickly ignore carbon dioxide (CO2) management methods, oblivious to environmental externalities and development-related consequences (Welsch, 2004). According to the existing literature surrounding environmental degradation and sustainability, researchers and academicians have invested their time and efforts in unleashing the way of lessening the environmental adversity with the accommodation of green energy and policies implementation. In managing environmental diversification for sustainability, many researchers have examined the role of environmental innovation, energy efficiency, and good governance by taking into account either country specifics or/and panel data (Adebayo and Kirikkaleli, 2021; Alsahlawi et al., 2021; Khan et al., 2021; Qamruzzaman, 2021a; Nepal et al., 2021; Qamruzzaman, 2021b; Zhang et al., 2021). However, focusing on environmental sustainability with G7 economies, very few studies have been performed in empirical assessment, see, for instance, Hasnat et al. (2018), Murshed (2020), Amin et al. (2022).

The motivation of the study is to gauge the role of environmental innovation, energy efficiency, and institutional quality in managing environmental sustainability in the G7 economy for the period 1980–2020. The study has implemented several econometrical tools, including a cross-sectional dependency test, long-run cointegration by applying an error correction model, explanatory variables magnitudes on environmental sustainability detected through CS-ARDL, and directional causality. According to the coefficients, the association with environmental sustainability is negative and statistically significant, implying that environmental innovation, energy efficiency, and institutional development support environmental quality management. On policy ground, it is suggested that effective environmental policies formulation and implementation, along with the efficient institutional presence in the economy, can boost the present state of environmental development by lowering the ecological imbalance in the G7 countries.

As a case study, we considered several facts that have guided G7 nations and the selection of the sample. First, the policies and actions of these seven major economies, which together account for over half of global GDP, are crucial. According to the G7 nations' efforts to reduce CO2 emissions, the G7 countries accounted for 70% of early twentieth-century greenhouse gas emissions in 2012, compared with just 24% in 2012. Still, although China's absolute contribution to greenhouse gas emissions is significant, the G7's contribution was barely half that of China's in early 2010 (Wang and Su, 2020). Second, among the G7 countries, Canada has the highest per-capita greenhouse gas emissions and energy usage. Canada's climate policy performance is evaluated as "medium" as long as it continues to encourage the use and development of fossil fuels. When it comes to greenhouse gas emissions, the United States and Japan are relatively modest emitters and energy consumers compared with other wealthy countries. Third, the sample is intriguing because of the countries' non-homogeneous qualities. The findings of this study might aid the world's most powerful countries in better understanding how to adopt environmentally friendly policies.

The present study contributes to the existing literature in the following ground. First, with our best knowledge, for the first time, the nexus between environmental sustainability, environmental innovation, energy efficiency, and institutional quality in the G7 economy has been investigated. Second, the existing literature exposed two lines of thought regarding the measures of environmental sustainability; one line of study findings used the level of carbon emission as a measure for environmental sustainability (Adebayo and Kirikkaleli, 2021; Khan et al., 2021; Murshed et al., 2021; Riti et al., 2021), and another line of study findings considered newly offered variables that are ecological footprint as a proxy of environmental sustainability (Adebayo and Kirikkaleli, 2021; Murshed et al., 2021; Nath aniel, 2021). The contribution of the existing literature study has considered both variables as a measurement of environmental sustainability and unleashed the effects of environmental innovation, energy efficiency, and good governance in reaching a sustainable ecosystem by lowering environmental adversity. We firmly believe that conclusive evidence by accounting for environmental sustainability with diverse proxies may open an alternative avenue in environmental policy formulation and strategic implementation for managing a balanced eco-system.

The remaining stricture of the article is as follows: the literature review and hypothesis development are available in **Section 2**. Data, variables definition, and methodology of the study are reported in **Section 3**. **Section 4** displays the empirical model estimation and discussion, and the conclusion and policy suggestions are finely exhibited.

2 Literature Review

Climate change due to excessive greenhouse gas emissions has placed apex in every discussion and has tried to figure out the possible way of getting rid of it by eliminating carbon emissions in the atmosphere. Over the past decades, researchers, academicians, and policymakers have invested valuable efforts and time to unveil the different macro fundamentals of environmental sustainability. However, a consensus conclusion is yet to be established. Economic stricture, economic and financial integration, and industrial diversifications have to establish interlinkages among macro agents through the direct and indirect channels; however, the empirical findings with policy suggestions have revealed fruitful means in reducing environmental degradation to environmental sustainability. The presentation focused on examining the role of energy efficiency, technological innovation, and good governance on environmental sustainability in the G7 economy. By taking into account the exploratory relationship between independent and dependent variables, the literature survey was presented in the following manner.

2.1 Environmental Innovation

Environmental innovation comprises all the efforts of relevant entities (firms, unions, and private households) to produce new ideas, implement more efficient processes, or adopt new technology to reduce environmental burdens and achieve ecologically stipulated sustainability (Rennings, 2000). It is an excellent means of balancing economic growth with environmental protection and fostering long-term development (Aggeri, 1999). When economic expansion collides with environmental aims, environmental innovation's "public good" externality may restrict linked firms' incentives to invest in innovation.

According to the existing literature, three lines of evidence are available. The first line of researchers has invested time and effort in exploring the key determinants for fostering environmental innovation in the economy (Brunnermeier and Cohen, 2003; Kivimaa, 2007; Horbach, 2008; Liao, 2018; Liao et al., 2018; Biscione et al., 2021; Carfora et al., 2021). For fostering environmental innovation, the existing literature has suggested several factors, but many researchers have emphasized ensuring institutional quality, effective government policies, and environmental regulations. Second, contemporary performance research focuses mostly on the company level and often relies on data from industrial surveys or questionnaires (Eiadat et al., 2008; Sierzchula et al., 2012; Cai and Zhou, 2014). Using the data from the Jordanian chemical industry, Eiadat et al. (2008) argue that environmental innovation mediates and positively correlates with particular environmental pressures and economic success. Cai and Zhou (2014) investigate the internal and external drivers of environmental innovation (i.e., technical competence, environmental management systems, and innovation initiative), focusing on their roles in increasing firms' integrative capabilities.

The third line of finding is the nexus between environmental innovation and environmental sustainability. A growing number of researchers have documented the positive role of environmental innovation variables in managing environmental quality (Paramati et al., 2021; Lantz and Feng, 2006; Adebayo et al., 2022; Shahbaz et al., 2018). For example, Zhang et al. (2017) investigated the effect of environmental innovation on carbon emissions in China for the period 2000–2013 by applying the generalized system method of moments (SGMM) technique. The study reveals that most environmental innovation variables apply substantial impact to reduce carbon emission effectively. Moreover, Lee and Min (2015) assess the impact of green research and development investment for eco-innovation on environmental and financial performance for Japanese manufacturing firms from 2001 to 2010 by depending on the resource-based view and the natural resource-based view. The study reveals a negative relationship between green research and development and carbon emissions. Moreover, it is documented that energy innovation plays a beneficial role in improving environmental quality by reducing CO2 emissions.

Further evidence was found in the study of Kneifel (2010). The study advocated energy-efficient technology integration support to bring environmental sustainability by lowering the energy intensity, eventually decreasing carbon emissions. Particularly, the study reveals that energy use/ consumption can be decreased in new commercial buildings by 20 percent to 30 percent on average using conventional energy efficiency technologies. The decrease can be more than 40 percent for some building types and locations. These enhancements save money and energy and reduce a building's carbon footprint by 16 percent.

2.2 Energy Efficiency

First refers to energy efficiency and environmental sustainably nexus, existing literature has suggested that a growing number revealed a positive and statistically significant association between energy efficiency and environmental sustainability (see Akram et al. (2020), Hanley, McGregor (Hanley et al., 2009)). In a study, Sarkodie and Strezov (2019) suggested that energy usage significantly influences greenhouse gas emissions. Reduced greenhouse gas emissions depend on increased energy efficiency, clean and contemporary energy technologies such as renewable energy and nuclear power, and carbon capture and storage in fossil fuel and biomass energy-generating processes.

Using the EKC model, Balsalobre-Lorente et al. (2018) examine the connection between economic growth, energy innovation, renewable electricity consumption, natural resources abundance, trade openness, and carbon dioxide emissions in five countries (Germany, France, Italy, Spain, and the United Kingdom) during 1985–2016. The study reveals that renewable electricity consumption, energy innovation, and natural resources increase environmental quality. On the other hand, trade openness and the interplay between economic growth and consumption of renewable electricity have a beneficial effect on carbon dioxide emissions. Boutabba, (2014) investigated the long-run equilibrium and the existence and direction of a causal relationship between carbon emissions, energy consumption, financial development, trade openness, and economic growth for India from 1971 to 2008 by applying Granger Causality Test. According to the study, having a causality between per capita energy consumption and per capita carbon emissions in the long run, Sun et al. (2019) explained that green innovation and institutional quality substantially influence energy efficiency enhancement, controlling for some variables. Brännlund et al. (2007) investigate how exogenous technological advancement, in the form of an increase in energy efficiency, influences Swedish family consumption choices and, as a result, emissions of carbon dioxide, sulfur dioxide, and nitrogen oxide from 1980 to 1997. The study revealed that a 20% gain in energy efficiency would result in a 5% reduction in CO_2 emissions. Miao. (2022) has investigated the nexus between renewable energy consumption, globalization, and ecological footprint in newly industrialized countries (NICs) using annual data from 1990–2018 by employing the Method of Moments Quantile Regression (MMQR). Study findings documented positive and statistically significant effects of financial globalization and renewable energy consumption on environmental quality development.

2.3 Institutional Quality

Institutional economics research has certainly accepted that institutional quality is a crucial predictor of GDP growth since the pioneering works of Williamson (1989) and North (1990). Institutions use contextual constraints to develop and manage public norms and standards (Acemoglu and Robinson, 2010). Institutional quality is often connected with domestic institutions' policies that provide the legal and cultural framework for socioeconomic activity. As a result, it demonstrates the government's ability to develop and execute policies and regulations that stimulate the private sector, increase contract execution quality, safeguard property rights, uphold a strong rule of law, and protect institutions from political interference (Nguyen et al., 2018). On the other hand, poor institutions inefficiently support the private sector, resulting in corruption, ineffective bureaucracy, and lax environmental restrictions (Asoni, 2008).

Many researchers have been investigating the nexus between institutional quality and environmental sustainability/ development/quality (Rao and Hassan, 2011; Ibrahim and Law, 2016; Liu et al., 2020; Sarpong and Bein, 2020). For example, Abid (2017) examines the influence of economic, financial, and institutional developments on environmental degradation in 58 Middle East and African (MEA) and 41 European Union (EU) nations from 1990 to 2011. The study reveals that the quality of institutions demonstrates that excellent institutions have a direct and indirect impact on economic development and environmental quality in EU countries through the efficiency of public expenditure, the strengthening of financial development, and the attraction of FDI. In another study, Lau et al. (2014) expose the long-run relationship between CO_2 emission, exports, institutional quality, and economic growth and examine the causal relationship among these factors in Malaysia from 1984 to 2008 by applying autoregressive distributed lag (ARDL) bounds testing approach and Granger causality tests. The study reveals that a long-run relationship exists among the factors. Another result is that good institutional quality is vital for controlling CO2 emissions in economic development. Granger causality tests moreover confirm the significance of institutional frameworks in reducing CO2 emissions. In the same line of remarks available in the study of Bhattacharya, Awaworyi Churchill (Bhattacharya et al., 2017), Abid (2016) observes that political stability, democracy, government effectiveness, and corruption control negatively impact CO2 emissions. On the other side, regulatory quality and the rule of law positively impact CO2 emissions.

The study of Dadgara and Nazari (2017) investigated the effect of good governance on the environmental pollution in Iran as well as its competitors in the 2025 vision document (i.e., southwest Asian countries) for the period 2002–2015 by applying the covariate-augmented Dickey-Fuller (CADF) test and Pesaran cross dependence (DC) test. The study reveals that good governance (represented by accountability, government effectiveness, political stability, control of corruption, the rule of law, and quality of law) substantially impacts environmental pollution. Further evidence is available in the study of Tamazian and Bhaskara Rao (2010), Solarin et al. (2017), and Shan et al. (2021). The study of Allard et al. (2018) suggests that institutional quality improvements are critical for these nations. These results, however, do not agree with the findings of our sensitivity analysis, indicating that the indexes do not fully reflect the effect of change in institutional quality. Ronaghi et al. (2020) investigated the relationship between governance and economic performance and its effect on carbon dioxide emissions for OPEC countries from 2006 to 2015 by applying the spatial panel model. The study reveals that the governance index hurts CO2 emissions.

In a study, Sarkodie and Adams (2018) advocated that the quality of political institutions has a vital role in the social, governance, and economic readiness to assuage climate change and its effect. Moreover, Gani (Azmat Gani, 2012) investigates the link between five dimensions of good governance and CO2 emissions in 99 developing countries between 1996 and 2009, while data are available on various governance dimensions. The study established that political stability, control of corruption, and the rule of law are negatively and statistically substantially correlated with CO2 emissions per capita. Dkhili (2018) examines the relationship between environmental performance and institutions quality (represented by control of corruption, regulatory quality, government effectiveness, and the rule of law and act) in 48 developed countries and 139 developing countries from 2002 to 2015 GMM method. The study reveals that a strong institutional quality significantly improves developed countries' environmental performance. The findings can benefit developing countries since all factors indicate that all parameters reflecting institution quality declined environmental performance, except for government effectiveness, which has a positive and significant impact. Norouzi and Ataei (2021) examine the effect of good governance indicators on environmental quality in selected developing countries from 2000 to 2010 by applying the data panel model. The study reveals that good governance indices directly affect environmental quality in selected developing countries. Particularly, improving the governance indicators has guided in reducing degradation and enhancing the environment's quality.

3 Theoretical Development and Justification of the Study

Environmental legislation has long been an important element influencing environmental innovation (Porter and Linde, 1995). Indeed, when a corporation breaches environmental legislation, it exposes itself to legal action, penalties, and fines (Henriques and Sadorsky, 1996), which might lead to individual or class action litigation. As a result, we need to evaluate whether regulators can encourage environmental innovation. The relationship between environmental innovation and environmental sustainability has been explained with the environmental governance theory (Truffer and Coenen, 2012; Bergek et al., 2015). The influence of a regulatory framework on environmental innovation may be seen from two angles. To begin with, strict environmental restrictions may compel businesses to create and adopt a variety of eco-innovations. Firms' costs of complying with environmental regulations may rise due to their investments in pollution-prevention technology and the ensuing organizational changes. Significant expenses connected with environmental regulation, on the other hand, may operate as an incentive for businesses to enhance their internal efficiency (Porter and Linde, 1995; Boschma et al., 2017). As a result of higher resource productivity, eco-innovations may indicate a better and more cost-effective level of compliance with environmental requirements (Porter and Linde, 1995). Businesses develop novel manufacturing procedures that save basic resources and energy while repurposing trash. Second, environmental regulations may provide significant opportunities for firms above and beyond legal obligations. These firms may be able to shape future environmental rules, giving them a significant economic edge over less environmentally conscientious rivals (Markard et al., 2015). Furthermore, the lack of environmental rules may limit the incentives for businesses to pursue environmental changes. Environmental legislation, such as penalties for polluting corporations or regulations on pollutant emissions, may aid in internalizing the exterior harm caused by particular firms. In the absence of such environmental laws, competition between environmentally friendly and non-green inventions may be distorted (Khan et al., 2021).

The environmental governance theory highlights the relationship between institutional quality and environmental sustainability and the relationship exhibited in **Figure 1**. We need a strong environmental protection strategy, according to the theory. Environmental governance theorists claim that institutional quality and environmental sustainability are linked. According to the theory, a country's governance is important in guaranteeing effective environmental management because it mobilizes activists for environmental protection, which improves environmental quality and finally leads to sustainability (Harris and Sollis, 2003). As a result, the environmental governance theory provides the groundwork for predicting a positive relationship between institutional quality, environmental degradation, and environmental sustainability (**Table 1**).

The study has considered the theoretical motivation from the conceptual model discussed in the study of Hasanov et al. (2021). The study postulated that technological innovation, renewable energy integration, and export size assist in reducing the consumption-based carbon emission. The role of renewable energy has been extensively investigated especially focusing on environmental development (see Cuker et al. (2019), Venetsanos et al. (2002), Zhang and Liu (2019)). Renewable energy is environmentally friendly, unlimited, and regenerated quickly by nature. The demand for technological innovation to solve climate change

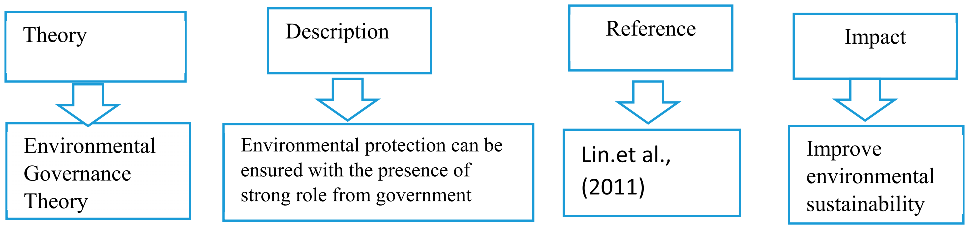

FIGURE 1 | Institutional quality and environmental sustainability.

TABLE 1 | Variable definition and sources.

Variable	Definition	Sources
Environmental sustainability	CO_2 emission per capita	WDI
	Ecological footprint (total GHA)	Global Footprint Network (Global Footprint Network, 2021)
Environmental innovation	Environment-related patents number	OECD (2020)
	No patent application	WDI
Energy efficiency	The ratio of renewable energy to fossil fuel consumption	Authors' construction
Institutional quality	Institutional composite indexed constructed by employing PCA	Authors' construction
Control variables		
Financial development	Domestic credit to the private sector (% of GDP)	WDI
FDI	FDI net inflow as a percentage of GDP	WDI

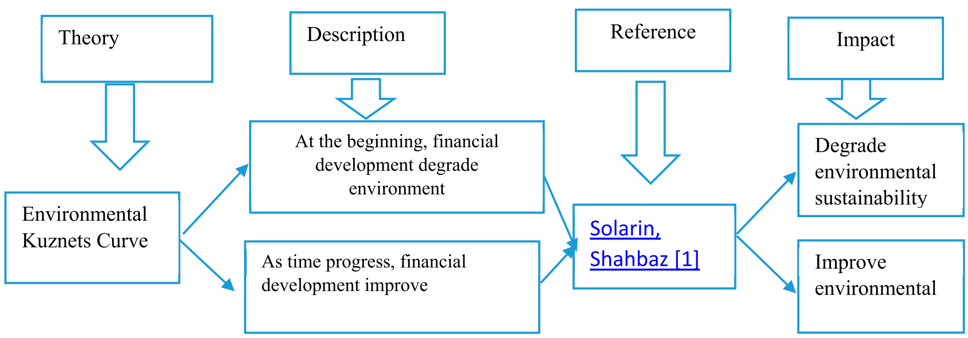

FIGURE 2 | Financial development, foreign direct investment, and environmental sustainability.

challenges, such as lowering the pace and volume of greenhouse gas concentrations in the atmosphere and averting the loss of the Earth's ozone layer, has risen due to increased reliance on renewable energy sources. Renewable energy sources also help to lessen our reliance on fossil fuels, which helps in the fight against global warming (Herring, 2000; Bleicher et al., 2014). Therefore, the inclusion of renewable energy not only ensures energy efficiency in the economy but also induces environmental development.

The empirical relationship between financial development, foreign direct investment, and environmental sustainability is explained in light of the Environmental Kuznets Curve (EKC), which is offered by Grossman and Krueger (1991) and is displayed in **Figure 2**. According to EKC, the first stage of financial development and FDI increases industrial activity, which increases carbon emissions and degrades environmental quality because economic growth takes precedence over a clean environment (Ahmed et al., 2022); however, in the second stage of financial development, foreign investment increases environmental quality because a sustainable environment takes precedence at this stage. As a result, the inverted U shape of EKC may be utilized to explain the connection between financial development, environmental degradation, and long-term environmental sustainability (Ahmed et al., 2020; Bibi and Jamil, 2021; Andriamahery and Qamruzzaman, 2022b; Qamruzzaman, 2022).

3.1 Hypothesis Development of the Study

The prime focus of the study is not to explore the key determinants of environmental sustainability for the G7 economy but rather to gauge the role of energy efficiency, environmental innovation, and institutional quality in

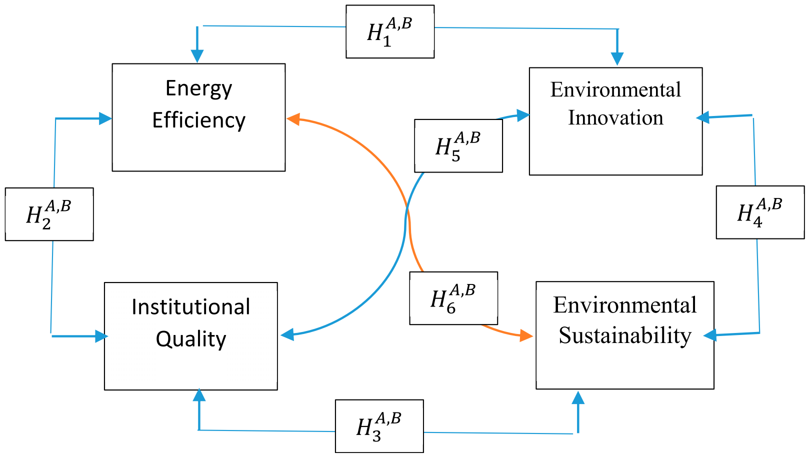

FIGURE 3 | Conceptual model for the study for hypothesis testing.

achieving environmental sustainability. Tanking accounts for the empirical association among variables, the following conceptual model has been proposed for testing the directional causalities (see **Figure 3**.)

The following hypothesis is to be tested:

$H_1^{A,B}$: Energy efficiency granger causes environmental innovation and vice versa.
$H_2^{A,B}$: Energy efficiency granger causes institutional quality and vice versa.
$H_3^{A,B}$: Institutional quality granger causes environmental sustainability and vice versa.
$H_4^{A,B}$: Environmental innovation granger causes environmental sustainability and vice versa.
$H_5^{A,B}$: Environmental innovation granger causes institutional quality and vice versa.
$H_6^{A,B}$: Energy efficiency grange causes environmental sustainability and vice versa.

4 DATA AND METHODOLOGY OF THE STUDY

4 1 Model Specification

Environmental sustainability has been a growing concern for everybody. Therefore, over the past decades, many researchers have been investing their time exploring the key determinants for managing environmental costs. In the line of empirical investigation, researchers have documented several critical macro fundamentals in environmental protection; however, their role in environmental sustainability differs from geographical and economic structural changes. The motivation of the study is to gauge the role of energy efficiency, environmental innovation, and institutional quality in managing environmental sustainability, that is, do all the explanatory variables augment or degrade the environmental sustainability in the G7 economy. The generalized empirical model is as follows:

$$\mathrm{ES\,(CO2EF)|EE,\,El,\,lQ} \tag{1}$$

where *ES* stands for environmental sustainability, *EE* stands for energy efficiency, *EI* for environmental innovation, and *IQ* denotes institutional quality. The variables proxies and data sources are displayed in table 1.

The natural log into **Eq. 1** can be transformed into the following empirical tested equation based on proxies measured for environmental sustainably. In **Eq. 2**, environmental sustainability is measured by carbon emission and **Eq. 3** deals with an ecological footprint as a measure of environmental sustainability.

$$ES(co2) = \alpha_0 + \beta_1 EE_{it} + \beta_2 EI_{it} + \beta_3 IQ_{it} + \beta_4 FD_{it} + \beta_5 FDI_{it} + \varepsilon_{i,t} \tag{2}$$

$$ES(EF) = \alpha_0 + \gamma_1 EE_{it} + \gamma_2 EI_{it} + \gamma_3 IQ_{it} + \gamma_4 FD_{it} + \gamma_5 FDI_{it} + \varepsilon_{i,t} \tag{3}$$

4.2 Variables and Descriptive Statistics

4.2.1 Environmental Sustainability

Economic sustainability without damaging the state of the environment is the prime idea of environmental sustainability because economic thriving at the cost of environmental degradation should not be ideal. Therefore, over the past decades, the issue of environmental protection through clean energy integration instead of reliance on fossil fuels in the industrial output is the reduction of carbon emissions in the atmosphere. According to the existing literature, two-line findings measure environmental sustainability by taking carbon emission (Khan et al., 2021; Qamruzzaman, 2021a; Hongxing et al., 2021) and ecological footprint (Hussain and Dogan, 2021; Murshed et al., 2021). Following the existing literature, we considered both proxies in measuring environmental sustainability to explore the inclusive and comparative assessment.

4.2.2 Energy Efficiency

In energy management, the idea of energy efficiency has recently been adapted in the light of carbon emission reduction through the integration of efficient energy sources such as renewable energies. The transition from conventional energy reliance on renewable energy sources significantly affects environmental quality development, ecofriendly industrial output, and sustainable economic progress. However, energy diversification with renewable sources demands substantial investment in energy sector growth. Owing to large capital investment, renewable sources' integration into the economic production process sometimes lingers. According to existing literature, there is no specific measure of energy efficiency. However, by taking into account the explicit definition and motivation of energy efficiency, we, for the first time, introduced the ratio of renewable energy consumption to fossil energy consumption. It is mentioned here that a higher ratio indicates a higher level of energy efficiency and lower carbon emission level in the economy.

4.2.3 Environmental Innovation

Innovation in environmental improvement involves integrating and applying for technological advances in carbon emission reduction with clean energy. Environmental innovation (EI) has emphasized incremental and radical changes in technological advancement in environmental and climate changes and diffusion and adaption in industrial growth. Environmentally inventive activity is at the heart of the regulatory–adoption relationship. The fear of more regulation is likely reflected in increased innovation. Innovative activity, in turn, results in greater standardization (Carrión-Flores and Innes, 2010) and is very certainly linked with businesses' adoption of already-existing environmental technology (Popp et al., 2010). Increased regulatory rigor facilitates the adoption of the most sophisticated technologies, allowing for greater standardization. In literature measuring the effects of environmental innovation on environmental sustainability or quality, two lines of research studies are available; first, a group of researchers measured environmental innovation by considering a number of the patent application which is extracted from the World development indicator (WDI) Zhang et al. (2017); Többelmann and Wendler (2020); Khan et al. (2021) and the second line of study considered the number of environmental-related technological innovation which is exported from OECD (see Khan et al. (2020), Cheng et al. (2019)). Considering the existing literature, we proceed with two proxies for exploring the conclusive evidence regarding the impact of environmental innovation on Environmental Sustainability. Furthermore, the study expects a positive association between environmental quality and innovation (Meng et al., 2021).

4.2.4 Institutional Quality

Institutional quality varies by country and by county. Due to institutional quality, environmental quality may be affected by institutional quality variations. Better policies are possible if strong institutions, such as sound laws, improved governance, and effective anti-corruption measures, protect the environment's quality by preventing FDI inflows into polluting sectors. A high-quality institution may aid in promoting renewable energy use and concentrate on the use of green technologies to preserve the environment's quality. Institutional quality such as the rule of law, bureaucracy, and corruption control is critical to environmental improvement, and inversely, institutional failure may harm ecosystems. Quality institutions work even if a country's wealth is poor. Improved environmental standards and regulations enhance environmental quality; for example, a legal and political framework, enough financial resources, feedback mechanisms, perceived ease of participation, and engaged people may be prioritized by governments to enhance institutional quality. Existing literature suggested that three dimensions of measuring the institutional quality in an empirical study are the corruption index (Goel et al., 2013; Hunjra et al., 2020), economic freedom index (Manca, 2010; Sun et al., 2021), and institutional quality index construction through PCA by taking into consideration of six blocs of institutional quality (Khan et al., 2021). Following the existing literature, in this study, we prefer to use the institutional quality index by employing the principal component analysis with the six criteria, namely Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, the rule of law, and Control of Corruption, mostly known as Kaufmann et al. (2010). The results of the PCA analysis are displayed in **Table 2**.

4.2.5 Financial Development

Financial development has a substantial influence on long-term economic growth and environmental preservation and promotes green economic growth, energy conservation, and environmental protection technologies (Charfeddine and Ben Khediri, 2016; Cheng et al., 2017; Destek and Sarkodie, 2019). Environmental conservation and green development studies are increasingly examining the repercussions of conservation on the economy and the financial sector, rather than only the environment's direct impact. They include, but are not limited to, financial assistance for breakthrough technologies, the development of environmentally friendly firms, and economic stimulation (Xu et al., 2021). Financial growth enables enterprises to spend more freely, which significantly influences environmental performance. On the one hand, some of the consequences may be beneficial since they encourage investment in emission-reduction technologies. Due to environmental constraints and consumer demand for eco-friendly items, such investments benefit companies (Mehta, 2021; Li and Qamruzzaman, 2022; Zhuo and Qamruzzaman, 2022). Thus, if enterprises can get external finance more quickly or at a lesser cost, environmental technology adoption will be hastened or cheaper.

4.2.6 Foreign Direct Investment

The impact of foreign direct investment on environmental issues has recently received much attention, both macro economically and locally. Foreign direct investment (FDI) has raised concerns among governments and the international community that it may have a macroeconomic effect on host countries' natural surroundings (Pao and Tsai, 2011; Asghari, 2013; Bhujabal et al., 2021). When it comes down to it, businesses want FDI regardless of the ramifications for the environment (Li et al.,

TABLE 2 | Principal components analysis.

Eigenvalues: (Sum = 6, average = 1)				**Cumulative**	**Cumulative**	
Number	**Value**	**Difference**	**Proportion**	**Value**	**Proportion**	
V	2.030832	0.836007	0.3385	2.030832	0.3385	
Ps	1.194825	0.138544	0.1991	3.225657	0.5376	
GE	1.056281	0.266011	0.1760	4.281938	0.7137	
RQ	0.790270	0.095811	0.1317	5.072208	0.8454	
L	0.694459	0.461127	0.1157	5.766667	0.9611	
CC	0.233333	---	0.0389	6.000000	1.0000	
Eigenvectors (loadings)						
Variable	**v**	**ps**	**GE**	**RQ**	**L**	**CC**
V	0.606065	-0.104628	0.331622	–0.081171	–0.061121	–0.708125
Ps	0.184381	0.655866	–0.121268	–0.652833	0.303590	0.052737
GE	–0.208214	0.345969	0.693959	0.375948	0.462467	0.012654
RQ	0.213111	0.640245	–0.203720	0.510641	–0.491784	–0.023693
L	0.602363	–0.137879	0.329633	–0.027345	–0.117311	0.703549
CC	0.383509	–0.101359	–0.493539	0.405440	0.659249	0.008704
Ordinary correlations	**v**	**ps**	**GE**	**RQ**	**L**	**CC**
V	1.000000					
Ps	0.122746	1.000000				
GE	–0.102276	0.007962	1.000000			
RQ	0.102934	0.240197	0.018915	1.000000		
L	0.764587	0.073313	–0.113800	0.109432	1.000000	
CC	0.256391	0.057318	–0.233628	0.133061	0.252961	1.000000

2019). As an explanatory variable, FDI is expressed by the ratio of net inflows of FDI to GDP. FDI may help host nations improve their technical, managerial, and environmental infrastructure by enhancing capital accumulation and productivity (Akinlo and Dada, 2021). Increased FDI will positively impact the host nations' technological advancements, technological inventions, and patent licensing, all of which will reduce local pollutants and boost their ES. On the other hand, it is harmed by FDI. There may be a decrease in environmental quality due to foreign direct investment (FDI) (Shahbaz et al., 2015).

4.3 Estimation Strategy

4.3.1 Correctional Dependency

Cross-sectional dependence is critical in panel data empirical research, especially when representative nations have comparable economic characteristics, such as developing countries, rising economies, and transition economies (Qamruzzaman and Jianguo, 2020). Owing to the internationalization of trade, financial integration, and globalization, a comparable economy is susceptible to any shock in other nations (Jia, 2021). As a result, examining the existence of cross-sectional dependence is most likely a need for empirical research using panel data. In the investigation, there are four tests that have been widely used. Breusch and Pagan proposed the Lagrange multiplier (LM) test, the Lagrange multiplier (CD_{lm}) that is the scaled version of the LM test following Pesaran. (2004), CD test following Pesaran. (2006), and Pesaran et al. (2008) proposed the bias-adjusted LM test, which is preferred in a situation when the cross-section (N) is smaller than time (T). Based on the following equation, we can construct LM test statistics:

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it} \qquad i = 1 \ldots\ldots N, t = 1 \ldots\ldots T \tag{4}$$

where y_{it} denotes a dependent variable, x_{it} are the independent variable, and the subscripts of t and I represent cross-section and period, respectively. The coefficients of α_i and β_i represent the country-specific intercept and slope in the equation. In the contest of the LM cross-section dependency test, the null hypothesis of cross-section independence — H_O = COV $(u_{it}u_{jt}) = 0$ for all t, and t≠j, against the alternative hypothesis of cross-sectional dependence — — H_O = COV $(u_{it}u_{jt}) \neq 0$ for at least t≠j. Moreover, the LM test statistics can compute with the following equation:

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{IJ \to d} X^2 N(N+1)2 \tag{5}$$

where $\hat{\rho}_{ij}$ represents the pairwise correlation of the residuals.

The LM test is not suitable in a situation with a larger cross-section (N); therefore, to overcome this limitation, Pesaran. (2004) suggests the following Lagrange multiplier (CD_{lm}) that is the scaled version of the LM test:

$$CD_{lm} = \sqrt{\frac{N}{N(N-1)}} \sum_{I=1}^{N-1} \sum_{J=i+1}^{N} \left(T\hat{\rho}_{ij} - 1\right) \tag{6}$$

In the case of larger N relative to T, CDlm estimation is subject to size dissertation. Therefore, Pesaran. (2006) proposed the following CD test, which is suitable in a situation when N is larger than T:

$$CD_{lm} = \sqrt{\frac{2T}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\hat{\rho}_{ij}\right) \tag{7}$$

Furthermore, the CD test might produce distorted information when the average pairwise correlation is zero, and the individual pairwise correlation is nonzero. Limiting the negative effect, Pesaran et al. (2008) proposed the bias-adjusted LM test. LM_{adj} utilized the exact mean and variance of the LM statistics in case of the large panel first $t \rightarrow \infty$ and then $N \rightarrow \infty$. The bias-adjusted LM statistics can compute with the following equation:

$$CD_{lm} = \sqrt{\frac{2}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\frac{(T-K)\hat{\rho}_{ij}^{2}-u_{Tij}}{v_{Tij}^{2}}\right)\vec{d}(N,0) \tag{8}$$

where k refers to the number of regresses, u_{Tij} and v_{Tij}^2 specify the mean and variance of $(T-K)\hat{\rho}_{ij}^2$, respectively.

4.3.2 Panel Unit Root Test

The discovery of the properties of variables in empirical estimation has been considered a critical step, especially in panel data assessment. Detecting variables' stationarity properties study applied three first-generation unit toot tests such as Levin et al. (2002), Im et al. (2003), and ADF—Fisher Chi-square (Maddala and Wu, 1999). However, due to the issue of cross-sectional dependency (CSD), the study utilized second-generation unit root tests that cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectionally augmented Im Pesaran and Shin (CIPS) familiarized by Pesaran. (2007). The framework for unit root test with CADE following Pesaran. (2007) is as follows:

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \vartheta_i \bar{y}_t + \tau_{it} \tag{9}$$

Putting long term in **Eq. 9** results in the subsequent **Eq. 10**:

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \sum_{k=1}^{p}\gamma_{ik}\Delta y_{i,k-1} + \sum_{k=0}^{p}\gamma_{ik}\overline{\Delta y}_{i,k-0} + \tau_{it} \tag{10}$$

where $Y_{it}-1$ and $\bar{y}_{t-1}$ stand lagged level average and first difference operator for each cross-section, the CIPS unit root test is displayed in **Eq. 11**.

$$CIPS = N^{-1}\sum_{i-1}^{N}\partial_i(N,T) \tag{11}$$

where the parameter $\partial_i(N,T)$ explains the test statistics of CADF, which can be replaced in the following manner:

$$CIPS = N^{-1}\sum_{i-1}^{N}CADF \tag{12}$$

4.3.3 Westerlund Cointegration Test

After confirming the presence of stationarity in research variables, the next stage in panel data analysis examines the long-run cointegration of the series under consideration. Given the concerns regarding CSD and heterogeneity, we needed second-generation panel cointegration tests, which offer precise and trustworthy information on the long-run cointegration relationship across variables in various settings. To overcome the earlier issue, the study preferred to apply error correction-based cointegration introduced by Westerlund. (2007). The error correction-based cointegration test produces two sets of output: two group test statistics (G_t and G_a) and two-panel test statistics (P_t and P_a), respectively. The null hypothesis of Westerlund cointegration is the absence of long-run association between FDI, FDI, GLO, and EC in BRI countries.

The error correction techniques for long-run cointegration assessment are as follows:

$$\Delta Z_{it} = \partial_i^{'} d_i + \varnothing_i\left(Z_{i,t-1} - \delta_i^{'} W_{i,t-1}\right) + \sum_{r=1}^{p}\varnothing_{i,r}\Delta Z_{i,t-r} + \sum_{r=0}^{p}\gamma_{i,j}\Delta W_{i,t-r} + \epsilon_{i,t} \tag{13}$$

The results of group test statistics can be derived with **Eqs 14**, **15**.

$$G_T = \frac{1}{N}\sum_{i-1}^{N}\frac{\varphi_i}{SE\varphi_i} \tag{14}$$

$$G_a = \frac{1}{N}\sum_{i-1}^{N}\frac{T\varphi_i}{\varphi_i(1)} \tag{15}$$

The test statistics for panel cointegration can be extracted by implementing **Eqs 16**, **15**:

$$P_T = \frac{\varphi_i}{SE\varphi_i} \tag{16}$$

$$P_a = T\varphi_i \tag{17}$$

4.3.4 CS-ARDL

Note, nonetheless, that panel ARDL undertakes errors that are cross-sectionally independent. Nevertheless, such perceived notions might produce spurious estimations in some situations and lead to badly predisposed estimates if the regressors' unobserved common factors are correlated (Yang et al., 2021; Zhuo and Qamruzzaman, 2021). Chudik and Pesaran. (2015) propose implementing (Pesaran., 2006) common correlated effects (CCE) approach in the context of panel ARDL models. Pesaran. (2006) displays the average values used in the equation to represent unobserved common factors as a proxy for dependent and independent variables. Therefore, when averaging **Eq 16**, **17** across *time,* we obtain

$$\overline{ES}_{it} = \bar{\alpha}_{it} + \sum_{j=1}^{p}\bar{\beta}_{ij}\overline{ES}_{i,t-j} + \sum_{j=0}^{q}\bar{\gamma}_{ij}\bar{Q}_{i,t-j} + \bar{\omega}_t^{'}G_t + \bar{\epsilon}_{it} \tag{18}$$

where, $\bar{\alpha}_{it} = \frac{\sum_{i-1}^{N}\alpha_i}{N}$

TABLE 3 | Cross-sectional dependency and homogeneity test.

	Panel A: cross-sectional dependency test				Panel B: slop of homogeneity	
	LM_{BP}	LM_{PS}	CD_{PS}	LM_{adj}	Δ	Adj.Δ
ES1	266.011***	28.24***	124.972***	32.114***	25.997	110.562
ES2	320.732***	23.946***	102.682***	27.416***	91.453	151.527
EE	234.401***	27.139***	195.329***	24.093***	21.869	129.886
EI	278.193***	44.153***	146.765***	53.273***	80.688	118.078
IQ	358.137***	40.565***	249.579***	10.949***	35.555	73.362
FDI	228.358***	24.742***	127.764***	40.603***	16.862	109.993
FD	308.094***	43.824***	243.107***	50.704***	92.052	65.48

$$\overline{ES}_{t-j} = \frac{\sum_i^N ES_{i,t-j}}{N}, \quad \bar{\beta}_j = \frac{\sum_i^N \beta_{i,j}}{N}\, j = 0, 1, 2\, p$$
$$\bar{Q}_{t-j} = \frac{\sum_i^N Q_{i,\,t-j}}{N}, \quad \bar{\gamma}_j = \frac{\sum_i^N \bar{\gamma}_{i,j}}{N}, = 0, 1, 2\, q$$
$$\bar{\omega}_j = \frac{\sum_{i=1}^N \omega_i}{N},\ \bar{\varepsilon}_t = \frac{\sum_i^N \epsilon_{i,t}}{N}$$

The error term, εi, in **Eq. 6** is independently distributed across time and countries, mean congregates to zero (i.e., εt = 0) in root mean square error as $N \to \infty$. Therefore, the linear effects of both dependent and independents can establish in the presence of cross-sectional dependence in μi,

$$ES = \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} + \bar{\omega}_t^{'} G_t$$
$$\downarrow$$
$$\bar{\omega}_t^{'} G_t = \overline{ES}_{it} - \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} \tag{19}$$
$$\downarrow$$
$$G_t = \overline{ES}_{it} - \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} \Big/ \bar{\omega}_t^{'}$$

Thus, the panel CS-ARDL specification of **Eq. 2**

$$\overline{ES}_{it} = \epsilon_{it} + \sum_{j=1}^{p} \beta_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \gamma_{ij} \bar{Q}_{i,t-j} + \sum_{j=0}^{p} \bar{\partial}_t^{'} \bar{Z}_{i,t-j} + \epsilon_{it} \tag{20}$$

where $\bar{Z} = (\overline{EE}, \overline{EI}, \overline{IQ},)$ and $S_{\bar{Z}}$ is the number of lagged cross-sectional average; furthermore, **Eq. 24** can be reparametrized to the effects of ECM presentation of Panel CS-ARDL as follows:

$$\Delta ES_{it} = \alpha_i + \xi_i \left(ES_{it-1} - \omega_t^{'} Q_{it-1} \right) + \sum_{J=1}^{M-1} \gamma_{iJ} \Delta ES_{it-J} + \sum_{J=0}^{N-1} \beta_{ij} \Delta Q_{it-J}$$
$$+ \sum_{j=1}^{p} \lambda_j \overline{\Delta ES}_{i,t-j} + \sum_{j=0}^{q} \delta_j \overline{\Delta Q}_{i,t-j} + \sum_{j=0}^{S_{\bar{Z}}} \bar{\partial}_t^{'} \bar{Z}_{i,t-j} + \mu_{it} \tag{21}$$

where $\overline{\Delta ES}_{t-j} = \frac{\sum_i^N \Delta ES_{i,\,t-j}}{N} \overline{\Delta Q}_{t-j} = \frac{\sum_i^N \Delta Q_{i,\,t-j}}{N}$

4.3.5 Dumitrescu-Hurlin Panel Causality Test

The study implements the granger causality test following the procedure initiated by Dumitrescu and Hurlin. (2012), which can handle the issue of cross-sectional dependency and efficient estimation under smaller N and larger T (Akbas et al., 2013; Liu and Qamruzzaman, 2021b). The test uses individual Wald statistics that converge sequentially to a standard normal distribution and the average statistic's semi-asymptotic distribution characterized for a fixed T sample. The average Wald statistic of Dumitrescu and Hurlin's (2012) panel causality test is

$$Y_{it} = \alpha_i + \sum_{K-1}^{P} \gamma_{ik} Y_{i,t-k} + \sum_{K-1}^{P} \beta_{ik} X_{i,t-k} + \mu_{it} \tag{22}$$

This test has a special feature: it will consider the differing degrees of dependence and variability in the results. To allow for the concept of Granger causality, the examination relies on the Wald statistics of the different cross-sectional groups. The test forms the average statistic linked with the homogeneous null non-causality (HNC) hypothesis as

$$W_{NT}^{Hnc} = N^{-1} \sum_{i-1}^{N} W_{i,t} \tag{23}$$

This experiment contains the null hypothesis that a single process is the only trigger and the alternate hypothesis that a community of processes is the cause. This approach suggests that the null hypothesis of no association between time and some statistical measure is placed fourth to compare the alternative correlation hypothesis to a subset of the time sequence. The main aim is to investigate the overt and indirect impact of multiple indicators on one another. This test reveals that the harmonized Z-test statistic, adjusted for fixed T samples, also has a standard normal distribution, as shown here:

$$Z = \sqrt{\frac{N}{2P} \times \frac{T - 2P - 5}{T - P - 3}} \times \left[\frac{T - 2P - 3}{T - 2P - 1} \bar{W} - P \right] \tag{24}$$

5 EMPIRICAL MODEL ESTIMATION AND INTERPRETATION

Before implementing the target model in exploring the elasticities of EI, EE, and IQ on ES, the study has performed

TABLE 4 | Panel unit root test results.

	CIPS		CADF	
	At level	**Δ**	**At level**	**Δ**
ES1	−2.702	−3.186***	−1.055	−2.056***
ES2	−1.082	−7.292***	−1.739	−6.302***
EE	−2.467	−6.959***	−1.818	−5.561***
EI_1	−2.747	−2.123***	−2.371	−2.995***
EI_2	−1.074	−2.617***	−1.746	−2.292***
IQ	−1.9	−5.888***	−1.402	−6.052***
FDI	−1.338	−6.864***	−2.624	−6.502***
FD	−1.82	−5.742***	−2.271	−2.456***

a preliminary assessment with several econometrical tests, including slop of heterogeneity, cross-sectional dependency, unit root test, and panel cointegration test and baseline estimation. The results of cross-sectional dependency are displayed in **Table 3** and reveal that all the test statistics are statistically significant, suggesting the presence of cross-sectional dependency among research units. So we can assume that research units share certain common dynamism among them. The homogeneity results follow Hashem Pesaran and Yamagata. (2008) with the null hypothesis of "homogeneity" displayed in **Table 3** (see Panel B). The test statistic Δ and Adj.Δ are statistically significant, suggesting the heterogeneity among research variables.

In this study, by following Gengenbach et al. (2009), for assessing the order of integration, we applied the panel unit root test commonly known as CIPS, and CADF familiarized by Pesaran. (2007) instead of applying the conventional panel unit root test, namely, IPS, LLC, and Bretting. Most importantly, the CADF and CIPS unit root tests yield reliable results in the presence of cross-sectional independence. The results of the panel unit root test are exhibited in **Table 4**.

The next study performed a long-run association between environmental sustainability, energy efficiency, environmental innovation, and institutional quality by implementing conventional (Pedroni, 2004; Pedroni, 2001) and error correction-based panel cointegration tests (Westerlund, 2007). The results of long-run cointegration are displayed in **Table 5**. Considering the test statistics from Padroni cointegration, it is apparent that the maximum number of test statistics are statistically significant at a 1% level, suggesting the rejection of the null hypothesis: "no-cointegration." Alternatively a long-run association among research variables is established. Furthermore, the ADF test statistics revealed a long-run association by rejecting the null hypothesis. The study further implemented error correction-based cointegration to get more exact findings with robust estimation. The study documented the long-run association between environmental sustainability, energy efficiency, environmental innovation, and institutional quality in G7.

In the following, the study investigated the effects of energy efficiency, environmental innovation, and institutional quality on environmental sustainability by employing CS-ARDL, where carbon emission is treated as a proxy of environmental sustainability (ES, hereafter). The model estimated results are displayed in **Table 6**, including the long-run coefficient in Panel A and the short-run coefficient in Panel B.

Referring to the long-run coefficient from CS-ARDL, the study documented a negative and statistically significant linkage between energy efficiency and environmental sustainability with a coefficient of −0.0743, suggesting that by ensuring the energy efficiency, the G7 nations can manage the emission of carbon into the ecosystem that is energy transaction from fossil fuel to renewable energy reliance. More precisely, a 10% development in energy efficiency can decrease the present state of carbon emission by 0.7439% in the G7 economy. The study findings are in line with the existing literature (see, for instance. Rosenfeld. (1999), Clarke et al. (2008), Riti and Shu. (2016)). Dealing with the short-run assessment, it is apparent that CS-ARCL disclosed a negative (positive) and statistically significant association between energy efficiency and carbon emission with a coefficient of 0.0462. The study has suggested that energy transition to efficient sources can cause environmental degradation; however, the development effect is more prominent than degradation. The nexus between environmental innovation (EI hereafter) and environmental sustainability with CS-ARDL implementation the study unveiled a negative and statistically significant tie with a coefficient of −0.0876, suggesting that progress in environmental innovation reduces environmental adversity with the integration of environmentally friendly technology in industrial output, eventually decreasing carbon intensity in the economy. Referring to short-run assessment, the study documented a negative and statistically significant association in both model estimations with a coefficient of −0.0292. Environmental innovations increase environmental prosperity, according to Zhang et al. (2017), Többelmann and Wendler. (2020), and Tang et al. (2021). However, the findings contradict Khan et al. (2021). According to Hodson and Brown (Qamruzzaman et al., 2019), environmental innovation lowers energy costs and speeds up the transition to a low-carbon

TABLE 5 | Results of panel cointegration test.

	[1]	[2]	[3]	[4]
Gt	−13.307***	−12.571***	−11.492***	−10.603***
Ga	−11.552***	−8.216***	−12.916***	−6.928***
Pt	−7.315***	−10.633***	−8.03***	−11.502***
Pa	−13.504***	−11.396***	−7.723***	−13.815***

*Note: the superscripts of ***explain the statistical significance at a 1% significance level.*

TABLE 6 | Environmental sustainability measured by CO_2 emission.

	CS-ARDL	CS-ARDL
	[1]	[2]
Panel A: Long-run coefficients		
EE	−0.0743 (0.0168)[− 4.4037]	0.1056 (0.0162)[6.4901]
EI_1	−0.0876 (0.0114)[−7.6262]	
EI_2		−0.1566 (0.0936)[−1.6731]
IQ	−0.0794 (0.0231)[−3.4253]	−0.0925 (0.0435)[−2.126]
FDI	0.0766 (0.0186)[4.0978]	0.1271 (0.033)[3.8446]
FD	−0.1062 (0.0985)[−1.0784]	−0.1377 (0.0963)[−1.4287]
Panel B: Short-run coefficients		
ΔEE	0.0462 (0.0103)[4.4687]	0.0533 (0.052)[1.0238]
ΔEI	−0.0292 (0.0186)[−1.5703]	0.0679 (0.108)[0.6288]
ΔEI	0.0299 (0.0041)[7.1783]	0.0076 (0.0309)[0.2472]
ΔIQ	0.0671 (0.0169)[3.961]	−0.0049 (0.0301)[−0.1654]
ΔFDI	−0.0233 (0.0135)[−1.7189]	0.019 (0.0699)[0.2722]
ΔFD	−0.1805 (0.032)[−5.6346]	0.0023 (0.002)[1.1529]
ECT (-1)	−0.1846 (0.0972)[−1.8982]	−0.2616 (0.7996)[−0.3272]
H-test	0.6371	0.2274

Note: the value in () represents standard effort and in [] denotes t-statistics.

TABLE 7 | Dependent variable ecological footprint as a proxy for environmental sustainability.

	[1]	[2]
	CS-ARDL	CS-ARDL
Panel A: Long-run coefficients		
EE	0.1354 (0.022)[6.1439]	0.014 (0.0108)[1.291]
EI_1	−0.1128 (0.0362)[−3.1134]	
EI_2		−0.0344 (0.0137)[−2.5001]
IQ	0.1544 (0.0561)[2.7489]	−0.0859 (0.0145)[−5.8877]
FDI	0.0517 (0.0056)[9.1053]	0.1094 (0.0574)[1.9049]
FD	0.0158 (0.0011)[13.6595]	0.0361 (0.008)[4.4766]
Panel B: Short-run coefficients		
ΔEE	−0.0874 (0.0093)[−9.3101]	−0.0198 (0.0072)[−2.724]
ΔEI	0.0026 (0.0004)[5.3497]	0.0514 (0.0114)[4.5122]
ΔIQ	−0.0295 (0.0021)[−13.5983]	−0.0384 (0.0143)[−2.6852]
ΔFDI	0.0919 (0.0441)[2.0808]	0.1452 (0.0421)[3.4477]
ΔFD	0.0108 (0.0028)[3.8316]	0.033 (0.0051)[6.3669]
ECT (−1)	−0.0397 (0.0034)[−11.4409]	−0.0521 (0.0274)[−1.8981]
C	−0.1757 (0.0247)[−7.0999]	−0.0723 (0.0253)[−2.8555]
H-test	0.512	0.224

Note: the value in () represents standard effort and in [] denotes t-statistics.

economy. According to Cagno and Ramirez-Portilla, decreased carbon emissions are also attributed to environmental innovation (Zafar et al., 2020).

The role of institutional quality in environmental sustainability revealed negative and statistically significant CS-ARDL assessment with a coefficient of −0.0794, postulating that domestic institutions' effective and efficient role plays a catalyst role in improving the state of environmental progress by lowering the level of carbon emission in the economy. A 10% growth in institutional quality can positively develop environmental quality augmentation by 0.794% in the G7 economy. Our study findings are supported by the existing literature such as Khan et al. (2021), Tang et al. (2021). In a study, Abid. (2017) examine the influence of economic, financial, and institutional developments on environmental degradation in 58 Middle East and African (MEA) and 41 European Union (EU) nations from 1990 to 2011. The study reveals that the quality of institutions demonstrates that excellent institutions have a direct and indirect impact on economic development and environmental quality in EU countries through the efficiency of public expenditure, the strengthening of financial development, and the attraction of FDI. In another study, Lau, Choong (Abid. 2017) expose the long-run relationship between CO_2 emission, exports, institutional quality, and economic growth and examine the causal relationship among these factors in Malaysia from 1984 to 2008 by applying autoregressive distributed lag bounds testing approach and Granger causality tests. The study reveals that a long-run relationship exists among the factors. Another result is that good institutional quality is vital for controlling CO2 emissions in economic development. Granger causality tests moreover confirm the significance of institutional frameworks in reducing CO2 emissions. In the same line of remarks available in the study of Bhattacharya et al. (2017), Abid. (2016) observes that political stability, democracy, government effectiveness, and corruption control negatively impact CO2 emissions. On the other side, regulatory quality and the rule of law positively impact CO2 emissions (Qamruzzaman et al., 2019).

Referring to foreign direct investment's impact on environmental sustainability, it is apparent that inflows of FDI in the economy discourage green energy integration; alternatively, the conversational energy demand has increased, resulting in the further degradation of environmental sustainability. More precisely, a 10% increase in FDI inflows in the economy can accelerate environmental adversity by increasing the carbon emissions in the atmosphere by 0.766% and ecological imbalance deteriorates by augmenting ecological footprint by 1.217%. Study findings are suggesting that relax environmental regulation induces foreign investors for transferring their capital in those economy. Therefore, consumption of fossil fuel has exacerbated with the cost of environmental destruction. The coefficient of financial development has revealed negative and statistically significant with environmental deration, suggesting that the financial development promotes environmental quality in G7 nations. In particular, a 10% growth of financial development will result in environmental quality improvement by lowering carbon emission by 1.062% and ecological progress by correcting ecological footprint by 1.377%. The existing literature has supported our study findings (see Tang et al. (2021) and Zafar et al. (2020)) but contradicts the findings of Zafar et al. (2020).

Next, the study moves to implement empirical assessment by replacing the proxy measures of environmental sustainability: ecological footprint. The empirical estimation results are displayed in **Table 7**, including four model outcomes. According to the empirical model output displayed in col [1] to [4], it is apparent that environmental efficiency improves

TABLE 8 | Results of causality test: EI measured by the total number of patent.

	ES	EE	EI	IQ	FDI	FD
Panel A: Environmental sustainability measured by CO2						
ES		(4.8618)*** [5.1243]	(6.1222)*** [6.4528]	1.543 [1.6263]	(5.0361)*** [5.308]	(3.6365)** [3.8329]
EE	(4.7959)*** [5.0549]		(6.017)*** [6.3419]	(4.1891)** [4.4153]	(5.5738)*** [5.8748]	(2.8671)** [3.0219]
EI	(2.4197)* [2.5504]	(4.1859)** [4.412]		(4.1987)** [4.4254]	1.8724 [1.9735]	(3.3889)** [3.5719]
IQ	(5.3623)*** [5.6519]	(3.5781)** [3.7713]	(3.272)** [3.4487]		(3.3921)** [3.5753]	(4.5387)** [4.7838]
FDI	(6.0541)*** [6.3811]	1.2306 [1.297]	(6.1615)*** [6.4942]	1.5589 [1.6431]		(6.1976)*** [6.5323]
FD	1.1976 [1.2623]	(3.0754)** [3.2415]	1.3039 [1.3743]	1.6014 [1.6879]	(2.8235)* [2.976]	
Panel B: environmental sustainability measured by Ecological footprint						
ES		(2.6068)* [2.7475]	(2.0106)* [2.1192]	(5.984)*** [6.3071]	0.8097 [0.8535]	(5.0116)*** [5.2823]
EE	1.3145 [1.3855]		(2.7619)* [2.9111]	(2.4112)* [2.5414]	(6.2614)*** [6.5995]	(3.1445)** [3.3143]
EI	0.8554 [0.9016]	(3.2146)** [3.3882]		(2.0648)* [2.1763]	(3.1445)** [3.3143]	(3.9362)** [4.1487]
IQ	1.0106 [1.0652]	1.1615 [1.2242]	(4.6121)** [4.8611]		(5.6896)*** [5.9969]	(4.4452)** [4.6853]
FDI	(5.2656)*** [5.55]	1.8682 [1.9691]	(3.7938)** [3.9987]	(3.7874)** [3.9919]		(5.7577)*** [6.0686]
FD	(3.0882)** [3.2549]	(2.6556)* [2.799]	1.8427 [1.9422]	(4.2242)** [4.4523]	(3.8065)** [4.0121]	

environmental quality by reducing degradation adversity that improves the ecological footprint. According to the model coefficients, a 10% growth in energy efficiency can improve environmental sustainability by lowering carbon emission by 1.354% and correcting ecological imbalance by 0.14%. The study's results show that efficient energy integration in macroeconomic aggregation and industrial advancement may boost environmental quality development by minimizing the negative impacts of excessive carbon emissions in the ecosystem. The effects of environmental innovation on environmental sustainability are displayed in col (Solarin, 2013) with total patent as a proxy of environmental innovation and in col (Cardenas et al., 2016) with the proxy of the environmental-related patent in the respective assessment. Considering the sign of coefficient, it is established negative and statistically significant linkage with the ecological footprint, suggesting that innovation related to processing development and environmental advancement play a critical role in reducing the ecological imbalance, alternatively supporting augmenting Environmental Sustainability. More precisely, a 10% increase in environmental innovation can increase environmental sustainability by 1.128%, according to the CS-ARD estimation with total patent as a proxy. Furthermore, a 10% growth in environmental-related innovation increases environmental sustainability by 0.344% with CS-ARDL estimation. Study findings suggest that innovation focusing on environmental efficiency can trigger the progress of environmental sustainability by lowering the presence of environmental pollutants ingredients in the ecosystem. According to Hodson et al. (2018), innovation lowers carbon emissions via more efficient energy usage and cost-effective methods to minimize carbon dioxide emissions. Similarly, Cagno et al. (2015) demonstrated that innovation increases energy efficiency and therefore decreases reliance on nonrenewable energy sources, thus reducing pollution. Loredo et al. (2019) investigated the relationship between economic growth, innovation, and greenhouse gas emissions. They assert that innovation contributes to the economy's transition to sustainable energy and manufacturing.

For the short run, the coefficient of error correction term has revealed negative and statistically significant at a 1% level, suggesting the speed of long-run convergence due to short-run disequilibrium. According to the coefficient of ECT, the disequilibrium due to short-run shocks can be rectified at a speed of 0.0397 in model (Solarin, 2013) and by 0.0521 in model (Cardenas et al., 2016) per period.

Next, the directional association between environmental sustainability, energy efficiency, environmental innovation, institutional quality, FDI, and financial development has been investigated by implementing the Dumitrescu and Hurlin. (2012) Panel Causality Tests. The panel causality test results are displayed in **Table 8**, with carbon emission as a proxy for environmental sustainability in Panel A and Panel B with an ecological footprint as a proxy for environmental sustainability. The study documented several directional causalities, but we focused on seeing the causalities running from explanatory variables to environmental sustainability. The study has documented several directional causalities among research units, and we prefer to assess the directional effects on environmental sustainability from independent variables. For panel A, the study revealed bidirectional causality between environmental sustainability and energy efficiency [ES←→EE], institutional quality and environmental sustainability [IQ←→ES]. Moreover, unidirectional causality runs from environmental innovation, foreign direct investment, and financial development to environmental sustainability. Referring to causalities in Panel B, the feedback hypothesis revealed in explaining the causal association between energy efficiency and environmental sustainability [ES←→EE] and institutional quality and environmental sustainability [ES←→IQ]. Furthermore, environmental sustainability

TABLE 9 | Results of causality test: EI measured by environment-related patents number.

	ES	EE	EI	IQ	FDI	FD
Panel A: Environmental sustainability measured by CO2						
ES		(5.9373)*** [6.2579]	(6.1498)*** [6.4819]	(2.1264)* [2.2412]	(0.8034) [0.8467]	(4.2486)** [4.478]
EE	(2.2401)* [2.3611]		(2.5972)* [2.7374]	(3.1424)** [3.312]	1.3273 [1.3989]	(4.865)*** [5.1277]
EI	1.6896 [1.7809]	(1.0531) [1.11]		(2.3177)* [2.4429]	(3.3347)** [3.5148]	(2.9107)** [3.0679]
IQ	(5.4877)*** [5.7841]	(5.984)*** [6.3071]	(3.6014)** [3.7959]		(2.6386)* [2.7811]	1.6471 [1.7361]
FDI	(4.5015)** [4.7446]	(5.5706)*** [5.8714]	(3.6216)** [3.8172]	(5.052)*** [5.3248]		(5.0138)*** [5.2845]
FD	1.5738 [1.6588]	1.0435 [1.0999]	0.9266 [0.9767]	(3.6248)** [3.8206]	(5.1487)*** [5.4268]	
Panel B: environmental sustainability measured by Ecological footprint						
ES		(5.8235)*** [6.138]	(2.7842)* [2.9346]	1.0913 [1.1503]	1.017 [1.0719]	(3.2465)** [3.4218]
EE	(2.3634)* [2.491]		(2.4824)* [2.6165]	(6.2954)*** [6.6353]	(2.001)* [2.1091]	(4.5834)** [4.8309]
EI	(3.2369)** [3.4117]	(2.4027)* [2.5325]		(4.1137)** [4.3358]	(3.0935)** [3.2605]	(5.7332)*** [6.0428]
IQ	(2.8916)** [3.0477]	(4.6376)** [4.888]	(3.7545)** [3.9572]		(5.1657)*** [5.4447]	(3.8235)** [4.03]
FDI	(4.9564)*** [5.224]	(3.0977)** [3.265]	(5.4909)*** [5.7874]	(5.6068)*** [5.9095]		(3.3326)** [3.5125]
FD	(4.5621)** [4.8085]	(5.6184)*** [5.9218]	(1.9883)* [2.0956]	(5.5079)*** [5.8054]	(4.678)** [4.9306]	

prompts environmental innovation, financial development, and foreign direct investment with unidirectional causalities flowing between them.

Table 9 exhibits the directional causalities with environmental innovation measured by environmental-related patent numbers. Referring to causalities in panel A (B), the feedback hypothesis holds in explaining the causal association between EE←→ES; FDI←→ES; FD←→ES; FDI←→ES). Furthermore, unidirectional association documented EE→ES, EI→ES; and IQ→ES.

6 DISCUSSION OF THE FINDING

Ecological imbalance, environmental adversity, and environmental sustainability have become the intensifying agent in ensuring sustainable economic development worldwide. The cost of environmental protection has been adversely causing both the macro and micro fundamental agents that are critically significant in economic progress, precisely sustainable development. It implies that the industrialized economies believe that economic progress should bear a portion of environmental degradation; that is the pollution haven hypothesis. In contrast, unmanaged carbon emissions had an unbearable impact on the environment and poverty augmentation, decreased foreign capital inflows, and the pollution haul hypothesis. However, this study tried to reveal the role of energy efficiency, environmental innovation, and institutional quality in managing environmental concerns in the G7 economy.

Referring to energy efficiency impact on environmental sustainability, the study demonstrated that clean energy integration in economic aggregated output through industrialization increases environmental quality by lowering carbon emissions and ecological footprints. According to the empirical model output, it is apparent that environmental efficiency improves environmental quality by reducing degradation adversity that improves the ecological footprint. Study findings suggest that efficient energy integration in macro-economic aggregation and industrial progress that relies on renewable energy instead of fossil fuel for production can positively affect environmental quality development by reducing the detrimental effects of excessive carbon emission in the ecosystem. Usman and Hammar. (2021) established a negative statistically significant connection between renewable energy consumption and ecological footprint, suggesting that renewable energy sources will decrease the ecological footprint. Renewable energy use, in particular, has a statistically significant and negative effect on the ecological footprint. On the other hand, in a study, Nathaniel. (2021a) revealed that excessive energy consumption in terms of fossil energy has a positive linkage with environmental degradation, suggesting that fossil energy consumption has produced detrimental effects in deteriorating the ecological imbalance in the long run. Additionally, it is hypothesized that effective energy integration in macroeconomic aggregation and industrial progress based on renewable energy rather than fossil fuels can benefit environmental quality development by mitigating the negative effects of excessive carbon emission in the ecosystem. Usman and Hammar. (2021) showed a statistically significant negative correlation between renewable energy consumption and ecological footprint, implying that renewable energy sources would reduce the ecological footprint. Renewable energy, in particular, has a statistically significant and detrimental influence on the ecological footprint. On the other hand, Nathaniel. (2021b) discovered a positive correlation between excessive energy consumption in terms of fossil fuels and environmental degradation, indicating that fossil energy use has had a deleterious influence on degrading the ecological imbalance over time. Pollution in nations is rising due to rising energy demand for manufacturing, fueled by nonrenewable energy sources, destroying environmental quality. Our results imply that using fossil fuels for energy damages the environment and degrades environmental quality while using energy from renewable sources improves environmental quality. Our findings support the notion that renewable energy is good for the environment since it emits less carbon, but nonrenewable energy usage pollutes and destroys the ecosystem. In the long term, using renewable energy instead of nonrenewable energy improves the environment by replacing energy from polluting and fossil fuels with clean energy sources and reducing reliance on oil-exporting nations for energy imports. It indicates that renewable energy may be generated domestically, eliminating importing energy sources such as petroleum from other nations. On the other hand, renewable energy may be connected to direct sustainable development since access to these energy sources is simple, and it benefits the economy, improves health, and decreases social and environmental issues.

Investment in environmental development through innovation documented positive association in sample economy, suggesting technological innovation in production process limit excessive conventional energy consumption rather ensure energy efficiency. According to coefficients from both estimations, the study unveiled a negative and statistically significant tie, suggesting that progress in environmental innovation reduces environmental adversity with the integration of environmentally friendly technology in industrial output, eventually decreasing carbon intensity in the economy. Referring to short-run assessment, the study documented a negative and statistically significant association. Zhang et al. (2017), Töbelmann and Wendler. (2020), and Iqbal et al. (2021) have reinforced the belief that environmental innovations are beneficial for environmental prosperity, which is supported by our findings. However, the study findings contradict Khan, Weili (Khan et al., 2021). A study by Hodson et al. (2018) explained that environmental innovation ensures efficient energy integration by lowering energy cost and energy transition, eventually supporting to increase in environmental quality by lowering the level of carbon emission. Moreover, Cagno et al. (2015) advocated that environmental innovation encourages the economy to shift energy reliance from fossil fuel to renewable energy for industrial output, reducing carbon emissions. Furthermore, environmental innovation lessens reliance on conventional energy demand; that is, the energy transition from fossil fuel to renewable energy consumption has been initiated with the motivation of environmental protection. Environmental innovation refers to any measures performed by relevant entities (firms, unions, and private households) to produce new ideas, improve processes, or deploy new technology to lower environmental burdens and attain ecologically defined sustainability. As a result, it is a good way to balance economic expansion and environmental preservation and promote long-term development. When economic development collides with environmental aims, environmental innovation's "public good" nature may restrict associated businesses' incentives to invest in innovation.

Our study found that institutional quality improved environmental quality, implying that good governance, the rule of law, and human rights protection have led businesses to reduce carbon-intensive operational procedures. Furthermore, our findings show that government effectiveness in safeguarding environmental quality is satisfactory in the panel countries. Higher institutional quality reflects human life and the rule of law, which support economic freedom and market economies, which increase environmental quality. Referring to the institutional quality impact on environmental sustainability, the study documented negative and statistically significant linkage between them, suggesting that improvement in institutional quality boosts environmental quality by lowering carbon emission and adversity in ecological footprint. Our findings are in line with the existing literature such as Ahmad. (2021), Nguyen and Dinh Su. (2021), Ibrahim and Law. (2016), and others. The study of Abid. (2017) demonstrated that institutional quality improves environmental quality through the efficiency of public investment, domestic trade liberalization, foreign ownership, and financial efficiency. Furthermore, Salman et al. (2019) established that well-functioned institutions increase economic growth by lowering the environmental degradation cost that is strict environmental policy formulation and implementation can induce for injection of the pollutant ingredient in the economy. In general, institutional quality is linked to domestic institutions' policies to provide legal and cultural frameworks for socioeconomic activity. Thus, demonstrating the government's capacity to define and enact policies and regulations that promote the private sector, enhance contract quality, protect property rights, promote a strong rule of law, and ensure the institutions' independence from political interference (Phuc Canh et al., 2019). On the other side, weak institutions inefficiently support the private sector, resulting in corruption, ineffective bureaucracy, and lax environmental laws (Asoni, 2008). Strong institutions support the execution of energy laws and regulations while also encouraging renewable energy technologies. Strong institutions also aid in the prevention of corruption and the strengthening of the legal system. All institutions collaborate to ensure that environmental law is implemented to preserve environmental quality. Consequently, it is clear that high-quality institutions directly impact environmental policy and may help impoverished countries reduce pollution while simultaneously increasing income. As they exert control over other related factors such as service quality, civil rights, corruption, politics, and accountability, quality institutions may also facilitate technology spillover via FDI inflows. They also play a critical role in improving environmental governance to ensure resource utilization. Our findings virtually totally support the theoretical components of the institutional quality hypothesis.

7 CONCLUSION

The motivation of the study is to gauge the role of energy efficiency, environmental innovation, and institutional quality in achieving environmental sustainability in the G7 economy for the period 1980–2020. Several econometrical tools have been implemented for evaluating the empirical association and the key findings of the study as follows:

The study documented that environmental innovation, energy efficiency, and institutional quality have augmented the activities in ensuring the ecological balance by reducing carbon emissions and ecological improvement. In particular, the study documented a positive association between environmental innovation and environmental sustainability, suggesting that environmentally advanced technological development in the economy assists in managing environmental costs by lowering carbon emission and ecological degradation. Our finding is comparable to that of Lin and Zhu. (2019), Mensah, Long (Lin and Zhu, 2019), and Ali et al. (2021). By contrast, Yii and Geetha. (2017) discovered a negative correlation between technological innovation and carbon emissions in the short run but none in the long run.

According to study findings, energy efficiency has positively improved environmental quality in the G7 countries by lowering carbon emissions and lessening ecological degradation. The study postulated that integration and effective clean energy integration would boost the carbon reduction propensity; in this respect, the G7 nations have already implemented several policies to increase energy efficiency and conserve energy to reduce carbon emissions. The G7 environmental perfection policies aim to include the particular aspects of industries, technological advancements, market forces, and governmental laws that shape the pollution-free movement. In environmental development with energy efficiency, G7 is expected to commit to almost halving their emissions by 2030 relative to 2010. The United Kingdom is already going even further, pledging to cut emissions by at least 68% by 2030 on 1990 levels (58% reduction on 2010 levels). More importantly, technical capabilities and environmental considerations drive the search for creative activities throughout the biofuels sector's many technological stages.

Environmental innovation is green technology integration in the production process that acts as a catalyst in environmental development, suggesting the incentives for R&D, innovation, market imperfection, and externalities encourage G7 countries to invest in environmental innovation, assisting these countries in organizing the geographical distribution of polluting industries to protect their environment at a low economic cost. For environmental innovation, G7 has already committed to increasing their contributions to international climate finance to meet the target of mobilizing $100 bn a year, which will help developing countries deal with the impacts of climate change and support sustainable, green growth with green technological integration. Thus, the study suggests that environmental sustainability is the combined output with the collaborative development in innovation, focusing on energy-efficient technology.

The present study is not out of certain limitations: first, the study measured energy efficiency by the ratio of renewable energy consumption to total fossil fuel; in the future study, energy efficiency can be measured by deriving from implementing total factor efficiency measurement. Second, the present study considered the institutional quality index as a proxy for measuring institutional quality; for future studies, a single measurement can be used in assessing their role in environmental development and possibly will be beneficial for policies development. Third, in terms of methodological aspect, the future study can be initiated by taking account of nonlinearity that the asymmetric shocks of energy efficiency, environmental innovation, and institutional quality on environmental degradation can explore diverse insights which might be beneficial for both related policy formulating sounding energy and environment protection.

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

MQ: Introduction, Methodology, Empirical model estimation; LJ, First draft preparation, Final Preparation.

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