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Energy Use Greenization, Carbon Dioxide Emissions, and Economic Growth: An Empirical Analysis Based in China

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Developing countries are constantly facing the problem of environmental degradation. Environmental degradation is caused by the consumption of non-renewable energy for economic growth, but the consequences of environmental degradation cannot be ignored. The main purpose of this study is to investigate the relationship between three variables (i.e., energy use greenization, CO_2 emission, and economic growth) in the case of China using simultaneous equation modeling techniques and data for the period 2000–2018. The results indicate that (1) there is a long-term equilibrium relationship between energy use greenization, carbon emissions, and economic growth in China. Energy use greenization not only reduces carbon dioxide emissions but also promotes sustainable economic growth in China. (2) Carbon emissions and economic growth have promoted energy use greenization, indicating that the pressures of environmental climate and economic transformation in China have forced energy use greenization to a certain extent. (3) The contribution rate of energy use greenization to economic growth shows an inverted U-shaped trend that rises first and then decreases subsequently, while carbon emissions have a relatively large contribution rate to green energy use and economic growth. These results have far-reaching policy directions for the environmental sustainability goals of the Chinese economy.

Keywords: energy use greenization, CO_2 emission, economic growth, energy economics, China

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INTRODUCTION

Environmental issues, such as climate change and global warming, have become critical issues at the global level and have begun to pose a serious threat to sustainable development (Bekun et al., 2019; Yam et al., 2021). Owing to industrialization and urbanization, the world has experienced considerable economic growth over the past few decades (Li et al., 2021). Carbon dioxide emissions are likely to grow at the second-fastest pace on record this year as global economies recover from the COVID-19 recession and invest stimulus money into fossil fuels (Zheng et al., 2019a). Fossil fuels will remain an important source of the energy mix in many countries (Liang et al., 2022). The drastic economic development of the BRIC countries has led to a large number of environmental problems, especially the emission of carbon dioxide (Pata, 2021). Substantial economic growth is in one way or another related to fossil fuel consumption that produces large amounts of greenhouse gases (GHGs) in the environment, which warms the atmosphere (Pata and

Kumar, 2021; Yin et al., 2021). The increasing concentration of GHGs is primarily responsible for global warming and climate change. The production of GHGs is considered a major factor affecting carbon dioxide emissions (Wu et al., 2021). Climate change has certain adverse impacts on human health, and among many factors, carbon dioxide is the most important gas that deteriorates the environment and human health. Brazil, India, China, and South Africa are fast emerging economies (FECs) owing to their strong fundamental base and reliance on fossil fuel energy sources, leading to increased GHG emissions and adverse effects on human health (Liu et al., 2020). The European Union (EU) considers that renewable energy sources can mitigate the effects of climate change (Bekun et al., 2021c). Reducing CO_2 emissions has become the primary priority for all economies throughout the world. Countries ratified the United Nations Framework Convention on Climate Change in 1992 to slow the global climate crisis, which is also the premise and foundation of cooperation among countries worldwide. In 2015, the Paris Climate Change Summit established a sustainable development goal for 2030. With the rapid development of the Chinese economy, China's dependence on energy consumption is increasing every year. The overall energy consumption of China in 2018 was 4.644 billion tons of standard coal, 3.3% higher than the previous year, and the total carbon emissions were 2.5% higher than the preceding year (Zheng et al., 2020; Zhou et al., 2021). Although the proportion of coal consumption has decreased by 1.4% from the previous year, it still accounts for 59% of the total energy consumption (Liu and Cai., 2018). Based on the statistical report of the International Energy Agency (IEA), China is the world's largest emitter of CO_2 and carbon emissions still continue to increase rapidly. China is highly concerned about the climate change problem. China has increased its efforts to promote low-carbon development in recent years by efficiently reducing GHG emissions, effectively boosting the adaptive capacity of the climate and continuously improving systems and mechanisms of operation.

China has also contributed positively to the Paris Agreement's finalization, adopting stronger policies to achieve sustainable development by 2030 and carbon neutrality by 2060 (Chi et al., 2021). Zheng et al. (2019a) suggest that the energy intensity per person may greatly reduce CO_2 emissions from energy-related companies in China, and the gross domestic product (GDP) is a crucial factor influencing the increase in industrial CO_2 emissions. Renewable energy is considered an alternative to overcome global warming and an effective choice to continue fossil fuel growth (Zheng et al., 2019b). Renewable technologies help to reduce CO_2 emissions from conventional energy sources to achieve a sustainable energy consumption system (Asongu et al., 2018). Furthermore, energy-saving solutions can help close the gap between CO_2 emissions and economic growth, enabling long-term development. To achieve sustainable energy development, China needs to continuously promote energy use greenization, complete the economic transformation, control CO_2 emissions, and bear the responsibility of major countries to reduce CO_2 emissions from a strategic standpoint.

Thus, given this background, it is important to evaluate the nexuses between energy use greenization, CO_2 emissions, and economic growth in China. Some pioneering studies (Anwar, 2016; Ishaque, 2017; Shahzad et al., 2017) have empirically investigated the nexus between CO_2 emissions and macroeconomic variables on the economy as a whole. In China, only few studies exist on the relationship between energy use greenization, CO_2 emissions, and economic growth. Second, based on the generalized method of moments (GMM) and structural modeling, this study analyzes CO_2 emissions, energy use greenization, and economic growth by using simultaneous equations. The primary goal of using the simultaneous system approach is just to account for simultaneity issues to avoid potential problems in error estimations of econometric researchers (Baydoun and Aga, 2021). The results of this study will provide important information for the development of environment and economic growth policies.

The remainder of this study is structured in the following manner. First, we provide a literature review and the econometric models and data are then examined. Subsequently, empirical analysis and debate are presented. Finally, the findings are addressed, and the policy implications.

A BRIEF LITERATURE REVIEW

The literature has shown widespread concern about the links between energy use, economic growth, and CO_2 emissions. As mentioned previously, the present literature can be classified into three sections of research; the first section focuses on the relationship between energy use and economic growth. The relationship between energy and growth is of great interest to not only economists but also to policymakers, because of its significant policy implications. Some researchers suggest that both key macro-variables and economic growth are the most important pillars of energy use; thus, the application of these candidate series to energy development programs is advocated (He et al., 2021). Energy use directly and/or indirectly contributes to economic growth (Wu et al., 2021). Conversely, other studies showed that energy use is determined by economic growth and not vice versa (Lan et al., 2021); several studies also found that both true GDP and energy use are interdependent, and there is bidirectional causality between them (Bekun et al., 2021c). However, some studies found that there is no causal relationship between energy use and economic development (Bekun et al., 2021b; Fang et al., 2022). The development of clean energy has a positive impact on the economic growth of new EU members (Regulation of the European Parliament and of the Council, 2021). Moreover, renewable energy is a dynamic force for economic growth in the OECD and G-7 economies (Bekun et al., 2019). The development of renewable energy is an important part of green economic growth and it also depends on the implementation of environmental regulation policies, which have made important contributions to the development of renewable energy.

The second section focuses on renewable energy consumption and environmental issues. With the rapid development of green energy, more researchers have studied the fundamental contribution of green energy development to the mitigation of emissions at the national, regional, and world levels. Many recent studies have confirmed the beneficial effects of green energy on environmental quality (Bekun, 2022). For example, the use of green energy leads to a drop in CO_2 emissions (Bekun et al., 2021a; Irfan et al., 2022). The development of green energy has contributed significantly to environmental improvements in 85 developed and developing economies (Osobajo et al., 2020). In addition, several researchers have found a bidirectional causal relationship between green energy and environmental quality (Ahukaemere et al., 2020; Manta et al., 2020). However, the empirical results of some studies do not demonstrate a causal relationship between renewable energy consumption and environmental quality (Liu et al., 2021). Conversely, the exploitation of green energy has reduced CO_2 emissions in five selected African economies (Baydoun and Aga, 2021). In the face of economic growth trajectories, renewable energy is a panacea for sustainable development.

The third section of the literature examines the relationship between renewable energy and economic growth, and the validity of the Environmental Kuznets Curve (EKC) Hypothesis. According to the EKC hypothesis, the relationship between economic growth and environmental deterioration resembles an inverted U-shaped curve. Many scholars, such as Osobajo et al. (2020), have proven the inverted U-shaped relationship between economic growth and CO_2 emissions, but the "EKC hypothesis" was generally regarded as a phenomenon to be tested in the present research. In some existing studies, the inverted U-shaped curve confirms that the growth of low-income per capita intensifies environmental deterioration until it stabilizes at middle-income levels, at which point fresh growth leads to improved environmental conditions (Liu and Cai, 2018; Iqbal et al., 2022). Several studies have validated the EKC hypothesis in a single nation (Liu et al., 2019; Pata and Isik, 2021). However, the EKC hypothesis does not hold true for China (Pata and Aydin, 2020; Pata and Caglar, 2020). In five EU nations, there was an inverted U-shaped relationship between CO_2 emissions and economic development (Zheng et al., 2019a; Chen and Ma, 2021). Some studies found that economic growth boosts the usage of renewable energy (Chi et al., 2021). These findings suggest that the relationship between non-renewable energy, renewable energy, and economic growth appears to be U-shaped in the economy of India (Sarfraz et al., 2021). In the long run, CO_2 emissions have an N-shaped relationship with the real GDP per capita, rather than the traditional U-shaped curve given by the EKC hypothesis (Olivier and Peters, 2020). Through a comparative study, the economic growth in Australia accelerated CO_2 emissions. In the long run, Canadian trade appears to increase CO_2 emissions, while economic growth and urban population also boost CO_2 emissions (Shah et al., 2021).

Based on structural modeling and the GMM estimator, this study used simultaneous equations to analyze the relationship between energy use greenization, CO_2 emissions, and economic growth from an empirical research perspective, and the results were compared with those from existing research. The primary motivation for using the simultaneous system technology was to compensate for the simultaneity problems and prevent a potentially biased evaluation by econometric researchers (Hassan et al., 2019). The interconnection between economic growth, energy consumption, and CO_2 emissions has been examined extensively by researchers both at home and abroad, offering a solid framework for this research. China is rapidly developing as a country. China is the world's second-largest producer and consumer of energy and the second-largest emitter of CO_2. China faces enormous pressure from the international community to save energy and reduce emissions. The subject of this case study is the connection between China's energy use greenization, CO_2 emissions, economic growth, energy conservation, and emission reduction through energy policy and policy formulation.

Compared with that of previous studies, the marginal contribution of this study is as follows: first, based on the existing literature, the Cobb–Douglas production function model was used to introduce CO_2 emissions and construct a regression equation for carbon dioxide emissions. Second, an empirical study of the link between energy use greenization, CO_2 emissions, and economic growth was conducted through the simultaneous equation modeling approach. Third, this study uses the proportion of clean energy consumption such as natural gas, nuclear power, and hydropower in total energy consumption as a measure of energy use greenization.

MODEL BUILDING AND DATA

Model Building

To study the relationship between economic growth, CO_2 emissions, and energy use greenization, we used the Cobb–Douglas production function model, wherein the income is influenced by the level of technology, labor, and capital. Apart from these factors, energy as a potential factor in economic growth has also been cited (Rousseeuw and Yohai, 1984). Generally, the extended Cobb–Douglas production function is expressed as follows:

$$Y = AK^{\beta_1} L^{\beta_2} E^{\beta_3} e^{\varepsilon}, \tag{1}$$

where Y represents the income level; A represents the level of technology; K represents the capital; L represents the labor; E represents energy use; and β_1, β_2, and β_3, respectively, represent the output elastic coefficients of capital, labor, and energy use. There is a linear relation between CO_2 emissions (CE) and energy use, and at any time: E = b.CE at a specific level of technology. Furthermore, some energy economists discovered that renewable energy may reduce CO_2 emissions while also increasing economic growth; hence, renewable energy can be used as a component in the production function model (Tiwari, 2011; Mahjabeen, 2020; Venkatraja, 2020). Therefore, the extended Cobb–Douglas production function model is expressed as follows:

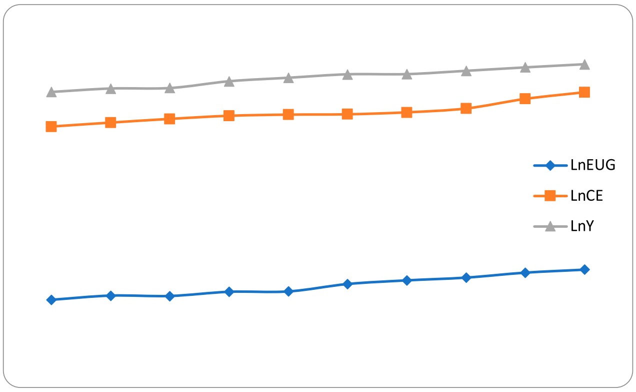

FIGURE 1 | Time series of lnEUG, lnCE, and lnY.

$$Y = AK^{\beta_1} L^{\beta_2} bCE^{\beta_3} RE^{\beta_4} e^{\varepsilon}. \quad (2)$$

We considered the logarithm of the Cobb–Douglas production function model **(2)** and obtained the following result:

$$\ln Y_t = \beta_0 + \beta_1 \ln CE_t + \beta_2 \ln EUG_t + \beta_3 \ln L_t + \beta_4 \ln K_t + \varepsilon_t, \quad (3)$$

where $\beta_0 = \ln A$; t is the subscript; T represents the time period; Y indicates the income level; CE indicates the CO_2 emissions per capita; EUG indicates energy use greenization; K represents the capital; L indicates labor; and ε is a random variable. The production function model was separated into multiple analysis models to inspect the relationship between energy use greenization, economic growth, and CO_2 emissions. These new models were established on the foundation of past theoretical and empirical research. Energy use greenization and CO_2 emissions can be used as the dependent or independent variables. To examine the causality of income, capital (K), labor (L), energy use (EU), squared GDP (Y^2), direct foreign investment (F), trade openness (T), oil prices (OP), financial development (FD), and urbanization (U) are defined as independent variables.

An empirical study of the link between energy use greenization, CO_2 emissions, and economic growth is conducted through the following three function models:

$$\ln Y_t = \beta_0 + \beta_1 \ln CE_t + \beta_2 \ln EUG_t + \beta_3 \ln K_t + \beta_4 \ln L_t + \varepsilon_t, \quad (4)$$

$$\ln CE_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln EUG_t + \beta_3 \ln Y_t^2 + \beta_4 \ln EU_t + \beta_5 \ln U_t + \beta_6 \ln F_t + \varepsilon_t, \quad (5)$$

$$\ln EUG_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln CE_t + \beta_3 \ln OP_t + \beta_4 \ln FD_t + \beta_5 \ln T_t + \varepsilon_t. \quad (6)$$

Model (4) shows that the GDP is affected by CO_2 emissions, renewable energy, labor, and capital (Danish et al., 2017). Model (5) indicates that the amount of CO_2 emissions is affected by the GDP per capita, renewable energy, energy use, squared GDP per capita, urbanization, and direct foreign investment (Lee and Brahmasrene, 2014). Model (6) indicates that energy use greenization is affected by the GDP, oil prices, CO_2 emissions, and external trade (Ishaque, 2017).

TABLE 1 | Descriptive statistics.

Variable	Mean	SD	Min	Max
CE_t	13.160	12.201	0.572	29.51
Y_t	3651	2026	5305.8	11,817.6
EUG_t	0.020	0.011	0.007	0.052
FD_t	0.412	0.132	0.189	0.603
F_t	1.756	2.632	-1.321	8.511
T_t	75.111	12.123	56.122	97.010
L_t	0.455	0.275	0.055	1.742
K_t	21.154	3.218	18.556	32.852
OP_t	47.701	30.102	15.521	100.514
U_t	0.445	0.273	0.054	1.746
EU_t	115.43	16.820	83.714	149.904

Models **(4–6)** are tested by using the GMM, which is a frequently used multidirectional model. The GMM can be used to solve the problem of endogeneity, and an effective and reliable evaluation is conducted when any heteroscedasticity occurs. In addition, two diagnostic examinations are required for estimating models **(4–6)**; namely, Hansen's test for excessive identification limits and Durbin–Wu–Hausman's (DWH) test for examining the issue of endogeneity (Engle and Granger, 1987). The first test provides proof of the validity of the instrumental variable. This tests the hypothesis that these instruments are suitable, and this hypothesis was consequently rejected. The second test was used to examine endogeneity issues in the three forecasted models. The alternative hypothesis affirms the endogeneity of the instruments. If the hypothesis is accepted, the technology of the instrumental variable is unsuitable.

Data and Descriptive Statistics

To evaluate models **(4–6)**, we collected the annual data of China from 2000 to 2018. These data are sourced from the Chinese Energy Statistic Yearbook and the Chinese Statistical Yearbook. To eliminate the possible heteroscedasticity problem, the horizontal time series data are processed by a natural logarithm to obtain lnEUG, lnCE, and lnY, as shown in **Figure 1**. **Figure 1** shows the changing trends of lnEUG, lnCE, and lnY. It shows that since 2000, the proportion of clean energy consumption in China generally transitioned from a slow increase (2000–2008) to a rapid increase (2009–2018); namely, from 5.5% in 2000 to 15.7% in 2018, indicating that China has achieved certain results in energy use greenization and energy consumption structure optimization. Simultaneously, although China's CO_2 emissions are increasing every year, the growth rate has slowed down significantly since 2012. This shows that the continuous optimization of the industrial structure and energy consumption structure has significantly reduced the growth rate of carbon emissions, even in 2016, which showed a negative growth of 0.3%. In addition, China's per capita GDP also showed a steady growth trend during the sample period, but the growth rate has declined in recent years.

TABLE 2 | Variable correlations.

Variable	CE_t	Y_t	EUG_t	FD_t	F_t	T_t	L_t	K_t	OP_t	U_t	EU_t
CE_t	1										
Y_t	0.701***	1									
EUG_t	-0.615**	0.150	1								
FD_t	0.691**	0.521**	0.705*	1							
F_t	0.284	0.163	0.322	0.540**	1						
T_t	0.558**	0.411	0.269	0.628*	0.728**	1					
L_t	0.420	0.499	0.498	0.702	0.309	0.436	1				
K_t	0.579	0.620**	0.371	0.624	0.477	0.415	0.535	1			
OP_t	0.561**	0.563***	0.620**	0.597**	0.581*	0633***	0.699*	0.584***	1		
U_t	0.401	0.519	0.310	0.400	0.381	0.469	0.601	0.506	0.604**	1	
EU_t	0.661***	0.401***	0.450*	0.489	0.503***	0.554***	0.400**	0.509*	0.593***	0.495*	1

Indicates significant paths: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

TABLE 3 | Simultaneous equation generalized method of moment estimation for the models.

Dependent variables						
Independent variable	**Y (GDP per capita) model (4)**		**CO_2 (CO_2 emissions) model (5)**		**EUG (EU greenization) model (6)**	
	Coef	**P**	**Coef**	**P**	**Coef**	**P**
Y (GDP per capita)			0.701	(0.000)	0.221	(0.031)
Y^2 (squared GDP)			-0.092	(0.061)		
CE (CO_2 emissions)	-0.102	(0.019)			0.245	(0.000)
EUG (EU greenization)	0.063	(0.000)	-0.050	(0.000)		
K (capital)	0.412	(0.000)				
L (labor)	-0.192	(0.059)				
EU (energy use)			0.411	(0.000)		
U (urbanization)			0.152	(0.022)		
F (foreign direct investment)			0.111	(0.043)		
OP (oil prices)					0.109	(0.125)
FD (financial development)					0.210	(0.029)
T (trade openness)					0.112	(0.098)
Constant	7.211	(0.000)	4.521	(0.009)	11.001	(0.000)
Hansen's test (p)	13.216	(0.674)	20.514	(0.301)	18.011	(0.430)
DWH test (p)	5.001	(0.032)	10.401	(0.003)	6.331	(0.033)

Table 1 shows that during the sample period, the GDP per capita ranged from 5,305.8 to 11,817.6 Yuan; the per capita CO_2 emissions ranged from 0.57 to 29.5 tons; and energy use greenization accounted for 0.007–0.054% of the total ultimate energy consumption.

Table 2 shows that the GDP and CO_2 emissions per capita showed the largest correlation, whereas the urbanization variable showed the lowest. Moreover, there is a significant negative relationship between CO_2 emissions and energy use greenization. Energy use greenization is positively correlated with the GDP per capita, which implies that increasing energy use greenization in the total ultimate energy use may reduce CO_2 emissions per capita and increase the GDP per capita.

EMPIRICAL RESULTS AND DISCUSSION

Through Hansen's test and the DWH test, the evaluation coefficients of models **(4–6)** are presented in **Table 3**. The empirical findings of model **(4)** indicate that CO_2 emissions show a significant negative correlation with the GDP. If the per capita CO_2 emissions increase by 1%, the economic growth is expected to decrease by about 0.1%. This result was confirmed by the survey results of Pata (2018), who showed that Turkey's GDP per capita had not reached a level to reduce environmental pollution, and the consumption of renewable energy was not a solution to reduce CO_2 emissions. However, China's energy use greenization has a remarkable impact on economic growth, which confirms the growth hypothesis. These results are supported by the cases of developing countries (Zheng et al., 2019a; Iqbal et al., 2019). In addition, the capital and labor force coefficients show significantly positive and negative correlations with the economic growth, respectively.

The empirical results of model **(5)** show that the per capita GDP influences CO_2 emissions per capita. The research shows that there is a positive relationship between the per capita GDP and per capita CO_2 emissions. If the GDP per capita increases by 0.1%, the CO_2 emissions per capita are expected to increase by about 0.70%. This shows that the improvement of economic growth worsens the environmental quality. This result was confirmed by the findings of Höhne et al. (2011) for 15 European countries. We found a negative correlation between energy use greenization and CO_2 emissions. If energy use greenization increases by 1%, CO_2 emissions per capita are expected to decrease by about 0.05%. This result is the same as that in the references (Shahzad et al., 2017). However, our result contradicts the findings of one of the references (Shabani and Shahnazi, 2019). Energy use shows a significant positive correlation with CO_2 emissions per capita. If energy use increases by 1%, the CO_2 emissions per capita are expected to rise by about 0.41%. Similarly, urbanization and trade openness have positive correlations with CO_2 emissions per capita.

Finally, the empirical findings of model **(6)** display that the GDP per capita is significantly positive for energy use greenization at a level of 5%. Energy use greenization is expected to increase by about 0.22% if the economic growth increases by 1%. This finding shows that there is a positive and significant relationship between energy use greenization and economic growth, which implies that the increase in economic growth will lead to an increase in energy use greenization. Regarding the environmental variable, we found a positive correlation between CO_2 emissions per capita and the demand for renewable energy. If CO_2 emissions per capita increase by 1%, energy use greenization is expected to increase by about 0.24%. These results show that CO_2 emissions per capita increase environmental degradation and promote the production and consumption of carbon-free sustainable energy, while lower CO_2 emissions lead to lower renewable energy consumption. We also found a positive correlation between financial development and the demand for renewable energy. If financial development increased by 1%, the energy use greenization was expected to increase by about 0.21%. This result showed that financial development was an important catalyst to promote production and energy use greenization in China.

The aforementioned results indicated that (i) energy use greenization promotes per capita GDP growth; (ii) increased economic growth leads to higher CO_2 emissions, and continued increases in CO_2 emissions may reduce economic growth; and (iii) increased CO_2 emissions can boost the demand for renewable energy, thereby reducing CO_2 emissions.

DISCUSSION AND CONCLUSION

The main objective of this study was to investigate the relationship between CO_2 emissions, energy use greenization, and economic growth. Our findings show that energy use greenization may have narrowed the gap between China's economic growth and CO_2 emissions from 2000 to 2018. This study tested these interrelations using the simultaneous equation model approach. This approach enables us to simultaneously examine the relationship between energy use greenization, CO_2 emissions, and GDP. Our empirical results show that energy use greenization can promote economic growth. We also found that economic growth leads to increased CO_2 emissions, which promotes energy use greenization. Our findings also emphasize that energy use greenization can narrow the gap between China's economic growth and CO_2 emissions.

The key policy implications emerging from the aforementioned results are as follows. First, we found a significant relationship between the GDP and CO_2 emissions. The results indicate that economic growth leads to an increase in CO_2 emissions, and the continuous increase of CO_2 emissions reduces economic growth. Hence, to solve the contradiction between energy supply and security, economic growth, and environmental protection, the Chinese government has promulgated the Energy Law of the People's Republic of China. The Chinese government encourages the development of clean energy and defines hydropower, nuclear energy, natural gas, coal-bed methane, wind energy, biomass energy, solar energy, geothermal energy, and ocean energy as clean and low-carbon energy. Moreover, energy greenization should be an important component of the CO_2 emission mechanism. Increased CO_2 emissions can increase the demand for energy use greenization, thereby continuously reducing CO_2 emissions. Second, there is a significant relationship between energy use greenization and CO_2 emissions. An increase in CO_2 emissions can increase the demand for energy use greenization and continuously reduce CO_2 emissions. High fossil fuel consumption and the sharp increase in CO_2 emissions have brought severe challenges to the sustainable development of China's economy. Energy structure transformation and CO_2 emission reduction have become important issues for China. Therefore, China is geographically well-positioned and has a high potential for the production of renewable energy from solar and wind energy. The Chinese government has increased the proportion of renewable energy usage in total energy consumption through measures to adjust the energy structure. In terms of economic and social aspects, the Chinese government not only encourages energy use greenization, but also provides funds to improve renewable energy consumption and industrial energy use. China implements green finance policies and reduces investments in high-polluting and high-emission industries. These measures will enable China to profit entirely from the interests of energy use greenization. On the one hand, energy use greenization is changing the traditional energy consumption structure, transitioning from coal-fired cogeneration in the past to distributed energy structures, combined natural gas cooling, heating, and power, and complementary clean and renewable energy. Simultaneously, the peak adjustment capacity of clean energy reserves should also be improved to expand its utilization scope. Conversely, owing to China's high demand for coal in the short term, the development and application of coal cleaning technology need to be accelerated, and black energy (coal) needs to be transformed into green energy.

SUGGESTIONS AND POLICY IMPLEMENTATIONS

We need to acknowledge the positive role of energy use greenization in reducing CO_2 emissions to achieve sustainable economic growth. Simultaneously, as a developing country, China should pay special attention to maintaining economic growth and employment stability in the process of energy use greenization. Therefore, it is necessary to promote the transformation of the traditional energy production industry (such as coal and oil industries) to mechanization and intelligence, transition from simple resource mining to deep processing, and eliminate the backward production capacity. Some manufacturing industries (with large traditional energy consumption, such as power production and supply industries) need to be encouraged to purchase green raw materials and green production equipment, increase the proportion of clean energy and renewable energy input, and realize energy use greenization from the production side. For the green energy-related industries (such as the new energy vehicle industry), policy support, including subsidies and research and development tax incentives, is required in the initial stage of enterprise incubation and green technology research.

On the one hand, energy use greenization requires changing the traditional energy consumption structure, from the cogeneration of coal and power to distributed energy, cold, heat, and electricity systems, and complementary clean energy and renewable energy. Simultaneously, the peak regulation capacity of clean energy reserves should also be improved to expand its scope of utilization. Conversely, because China still has a high demand for coal in the short term, the development and application of clean coal technologies should be accelerated; these include carbon emission control technologies, carbon sequestration (including carbon capture), and clean coal combustion technologies, including circulating fluidized bed combustion to promote the transformation of coal to green energy. This study intends to accelerate the market-oriented reform of energy and the power system, and promote the role of the market mechanism on the sides of power generation and sales. In addition, with the continuous development of China's green economy, the related green energy industry has a large capital gap. Therefore, it is necessary to comprehensively use green financial methods, such as green credit, to meet the capital needs in the process of energy use greenization.

This study discusses the relationship between energy use greenization, CO_2 emissions, and economic growth, and provides a theoretical basis and policy recommendations for the sustainable promotion of energy use greenization in China. However, this study was only conducted at the national level and can be conducted at the regional or industry level in the future.

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

WX: writing an initial draft. KI coordinated the work and writing—analysis. YW: proofreading.

REFERENCES

Ahukaemere, C. M., Okolo, N., Aririguzo, B. N., and Uchenna, O. S. (2020). Tropical Soil Carbon Stocks in Relation to Fallow Age and Soil Depth. *Malays. J. Sustain. Agric.* 4, 05–09. doi:10.26480/mjsa.01.2020.05.09

Anwar, J. (2016). Analysis of Energy Security, Environmental Emission and Fuel Import Costs under Energy Import Reduction Targets: A Case of Pakistan. *Renew. Sustain. Energy Rev.* 65, 1065–1078. doi:10.1016/j.rser.2016.07.037

Asongu, S. A., Le Roux, S., and Biekpe, N. (2018). Enhancing ICT for Environmental Sustainability in Sub-Saharan Africa. *Technol. Forecast. Soc. Change* 127, 209–216. doi:10.1016/j.techfore.2017.09.022

Baydoun, H., and Aga, M. (2021). The Effect of Energy Consumption and Economic Growth on Environmental Sustainability in the Gcc Countries: Does Financial Development Matter? *Energies* 14, 5897. doi:10.3390/en14185897

Bekun, F. V., Alola, A. A., Gyamfi, B. A., and Ampomah, A. B. (2021a). The Environmental Aspects of Conventional and Clean Energy Policy in Sub-Saharan Africa: Is N-Shaped Hypothesis Valid? *Environ. Sci. Pollut. Res.* 28, 66695–66708. doi:10.1007/s11356-021-14758-w

Bekun, F. V., Alola, A. A., Gyamfi, B. A., and Yaw, S. S. (2021b). The Relevance of EKC Hypothesis in Energy Intensity Real-Output Trade-Off for Sustainable Environment in EU-27. *Environ. Sci. Pollut. Res.* 28, 51137–51148. doi:10.1007/s11356-021-14251-4

Bekun, F. V., Emir, F., and Sarkodie, S. A. (2019). Another Look at the Relationship between Energy Consumption, Carbon Dioxide Emissions, and Economic Growth in South Africa. *Sci. Total Environ.* 655, 759–765. doi:10.1016/j.scitotenv.2018.11.271

Bekun, F. V., Gyamfi, B. A., Onifade, S. T., and Agboola, M. O. (2021c). Beyond the Environmental Kuznets Curve in E7 Economies: Accounting for the Combined Impacts of Institutional Quality and Renewables. *J. Clean. Prod.* 314, 127924. doi:10.1016/j.jclepro.2021.127924

Bekun, F. V. (2022). Mitigating Emissions in India: Accounting for the Role of Real Income, Renewable Energy Consumption and Investment in Energy. *Ijeep* 12, 188–192. doi:10.32479/ijeep.12652

Chen, Y., and Ma, Y. (2021). Does Green Investment Improve Energy Firm Performance? *Energy Policy* 153, 112252. doi:10.1016/j.enpol.2021.112252

Chi, Y., Bai, G., Li, J., and Chen, B. (2021). Research on the Coordination of Energy in China's Economic Growth. *PLoS One* 16, e0251824–20. doi:10.1371/journal.pone.0251824

Danish et al. (2017). 'Role of renewable energy and non-renewable energy consumption on EKC: Evidence from Pakistan'. *Journal of Cleaner Production* 156, pp. 855–864. doi:10.1016/j.jclepro.2017.03.203

Engle, R. F., and Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica* 55, 251. doi:10.2307/1913236

Fang, Z., Razzaq, A., Mohsin, M., and Irfan, M. (2022). Spatial Spillovers and Threshold Effects of Internet Development and Entrepreneurship on Green Innovation Efficiency in China. *Technol. Soc.* 68, 101844. doi:10.1016/j.techsoc.2021.101844

Hassan, S. T., Xia, E., Huang, J., Khan, N. H., and Iqbal, K. (2019). Natural Resources , Globalization , and Economic Growth : Evidence from Pakistan. *Environ. Sci. Pollut. Res.* 26, 15527–15534. doi:10.1007/s11356-019-04890-z

He, G., Liu, X., and Cui, Z. (2021). Achieving Global Food Security by Focusing on Nitrogen Efficiency Potentials and Local Production. *Glob. Food Secur.* 29, 100536. doi:10.1016/j.gfs.2021.100536

Höhne, N., Blum, H., Fuglestvedt, J., Skeie, R. B., Kurosawa, A., Hu, G., et al. (2011). Contributions of Individual Countries' Emissions to Climate Change and Their Uncertainty. *Clim. Change* 106, 359–391. doi:10.1007/s10584-010-9930-6

Iqbal, K., Hassan, S. T., Peng, H., and Khurshaid (2019). Analyzing the Role of Information and Telecommunication Technology in Human Development: Panel Data Analysis. *Environ. Sci. Pollut. Res.* 26, 15153–15161. doi:10.1007/s11356-019-04918-4

Iqbal, K., Hassan, S. T., Wang, Y., Shah, M. H., Syed, M., and Khurshaid, K. (2022). To Achieve Carbon Neutrality Targets in Pakistan: New Insights of Information and Communication Technology and Economic Globalization. *Front. Environ. Sci.* 9, 1–10. doi:10.3389/fenvs.2021.805360

Irfan, M., Elavarasan, R. M., Ahmad, M., Mohsin, M., Dagar, V., and Hao, Y. (2022). Prioritizing and Overcoming Biomass Energy Barriers: Application of AHP and G-TOPSIS Approaches. *Technol. Forecast. Soc. Change* 177, 121524. doi:10.1016/j.techfore.2022.121524

Ishaque, H. (2017). Quantifying the Potential Impact of Pakistan's GHG Mitigation Policies for Coal-Fired Power Plants. *Energy Procedia* 142, 2809–2815. doi:10.1016/j.egypro.2017.12.426

Lan, Z., Zhao, Y., Zhang, J., Jiao, R., Khan, M. N., Sial, T. A., et al. (2021). Long-term Vegetation Restoration Increases Deep Soil Carbon Storage in the Northern Loess Plateau. *Sci. Rep.* 11, 1–11. doi:10.1038/s41598-021-93157-0

Lee, J. W., and Brahmasrene, T. (2014). ICT, CO_2 Emissions and Economic Growth: Evidence from a Panel of ASEAN. *Glob. Econ. Rev.* 43, 93–109. doi:10.1080/1226508X.2014.917803

Li, Z., Wang, J., and Che, S. (2021). Synergistic Effect of Carbon Trading Scheme on Carbon Dioxide and Atmospheric Pollutants. *Sustainability* 13, 5403. doi:10.3390/su13105403

Liang, X., Lu, T., and Yishake, G. (2022). How to Promote Residents' Use of Green Space: An Empirically Grounded Agent-Based Modeling Approach. *Urban For. Urban Green.* 67, 127435. doi:10.1016/j.ufug.2021.127435

Liu, J.-L., Ma, C.-Q., Ren, Y.-S., and Zhao, X.-W. (2020). Do Real Output and Renewable Energy Consumption BRICS Countries. *Energies*, 1

Liu, J., Yang, Q., Zhang, Y., Sun, W., and Xu, Y. (2019). Analysis of CO_2 Emissions in China's Manufacturing Industry Based on Extended Logarithmic Mean Division Index Decomposition. *Sustainability* 11, 226. doi:10.3390/su11010226

Liu, Y., Jiao, R., Zhao, L., and Liu, K. (2021). Impact of Greenization on the Marginal Utility of Intensity of Carbon Emissions and Factors Affecting it in China. *Energy Eng. J. Assoc. Energy Eng.* 118, 363–378. doi:10.32604/EE.2021.013472

Liu, Z., and Cai, B. (2018). High-resolution Carbon Emissions Data for Chinese Cities. *Belfer Cent. Sci. Int. Aff.* Cambridge, Mass Harvard Univ. 1–29.

Manta, A. G., Florea, N. M., Bădîrcea, R. M., Popescu, J., Cîrciumaru, D., and Doran, M. D. (2020). The Nexus between Carbon Emissions, Energy Use, Economic Growth and Financial Development: Evidence from Central and Eastern European Countries. *Sustainability* 12, 7747. doi:10.3390/SU12187747

Olivier, J. G. J., and Peters, J. A. H. W. (2020). Trends in Global CO_2 and Total Greenhouse Gas Emissions. *PBL Neth. Environ. Assess. Agency* 2020, 70.

Osobajo, O. A., Otitoju, A., Otitoju, M. A., and Oke, A. (2020). The Impact of Energy Consumption and Economic Growth on Carbon Dioxide Emissions. *Sustainability* 12, 7965. doi:10.3390/SU12197965

Pata, U. K. (2021). Linking Renewable Energy, Globalization, Agriculture, CO_2 Emissions and Ecological Frootprint in BRIC Countries: a Sustainability Perspective. *Renew. Energy* 173, 197–208. doi:10.1016/j.renene.2021.03.125

Pata, U. K., and Aydin, M. (2020). Testing the EKC Hypothesis for the Top Six Hydropower Energy-Consuming Countries: Evidence from Fourier Bootstrap ARDL Procedure. *J. Clean. Prod.* 264, 121699. doi:10.1016/j.jclepro.2020.121699

Pata, U. K., and Caglar, A. E. (2021). Investigating the EKC Hypothesis with Renewable Energy Consumption, Human Capital, Globalization and Trade Openness for China: Evidence from Augmented ARDL Approach with a Structural Break. *energy* 216, 119220. doi:10.1016/j.energy.2020.119220

Pata, U. K., and Isik, C. (2021). Determinants of the Load Capacity Factor in China: A Novel Dynamic ARDL Approach for Ecological Footprint Accounting. *Resour. Policy* 74, 102313. doi:10.1016/j.resourpol.2021.102313

Pata, U. K., and Kumar, A. (2021). The Influence of Hydropower and Coal Consumption on Greenhouse Gas Emissions: A Comparison between China and India. *Water* 13 (10), 1387. doi:10.3390/w13101387

Pata, U. K. (2018). Renewable Energy Consumption, Urbanization, Financial Development, Income and CO_2 Emissions in Turkey: Testing EKC Hypothesis with Structural Breaks. *J. Clean. Prod.* 187, 770–779. doi:10.1016/j.jclepro.2018.03.236

Regulation of the European Parliament and of the Council (2021). Regulation of the European Parliament and of the Council Amending. *Eur. Comm.* 0197.

Rousseeuw, P., and Yohai, V., 1984, *Robust Regression by Means of S-Estimators*. 256–272. doi:10.1007/978-1-4615-7821-5_15

Sarfraz, M., Ivascu, L., Belu, R., and Artene, A. (2021). Accentuating the Interconnection between Business Sustainability and Organizational Performance in the Context of the Circular Economy: The Moderating Role of Organizational Competitiveness. *Bus. Strat. Env.* 30, 2108–2118. doi:10.1002/bse.2735

Shabani, Z. D., and Shahnazi, R. (2019). Energy Consumption, Carbon Dioxide Emissions, Information and Communications Technology, and Gross Domestic Product in Iranian Economic Sectors: A Panel Causality Analysis. *Energy* 169, 1064–1078. doi:10.1016/j.energy.2018.11.062

Shah, S. G. M., Sarfraz, M., and Ivascu, L. (2021). Assessing the Interrelationship Corporate Environmental Responsibility, Innovative Strategies, Cognitive and Hierarchical CEO: A Stakeholder Theory Perspective. *Corp. Soc. Responsib. Environ. Manag.* 28, 457–473. doi:10.1002/csr.2061

Shahzad, S. J. H., Kumar, R. R., Zakaria, M., and Hurr, M. (2017). Carbon Emission, Energy Consumption, Trade Openness and Financial Development in Pakistan: A Revisit. *Renew. Sustain. Energy Rev.* 70, 185–192. doi:10.1016/j.rser.2016.11.042

Wu, X., Liu, Z., Yin, L., Zheng, W., Song, L., Tian, J., et al. (2021). A Haze Prediction Model in Chengdu Based on Lstm. *Atmosphere* 12, 1479. doi:10.3390/atmos12111479

Yam, G., Tripathi, O. P., and Das, D. N. (2021). Modelling of Total Soil Carbon Using Readily Available Soil Variables in Temperate Forest of Eastern Himalaya, Northeast India. *Geol. Ecol. Landscapes* 5, 209–216. doi:10.1080/24749508.2019.1706295

Yin, L., Wang, L., Huang, W., Liu, S., Yang, B., and Zheng, W. (2021). Spatiotemporal Analysis of Haze in Beijing Based on the Multi-Convolution Model. *Atmosphere* 12, 1408. doi:10.3390/atmos12111408

Yuelan, P., Akbar, M. W., Hafeez, M., Ahmad, M., Zia, Z., and Ullah, S. (2019). The Nexus of Fiscal Policy Instruments and Environmental Degradation in China. *Environ. Sci. Pollut. Res.* 26, 28919–28932. doi:10.1007/s11356-019-06071-4

Zheng, J., Mi, Z., Coffman, D. M., Milcheva, S., Shan, Y., Guan, D., et al. (2019a). Regional Development and Carbon Emissions in China. *Energy Econ.* 81, 25–36. doi:10.1016/j.eneco.2019.03.003

Zheng, J., Mi, Z., Coffman, D. M., Shan, Y., Guan, D., and Wang, S. (2019b). The Slowdown in China's Carbon Emissions Growth in the New Phase of Economic Development. *One Earth* 1, 240–253. doi:10.1016/j.oneear.2019.10.007

Zheng, X., Lu, Y., Yuan, J., Baninla, Y., Zhang, S., Stenseth, N. C., et al. (2020). Drivers of Change in China's Energy-Related CO_2 Emissions. *Proc. Natl. Acad. Sci. U.S.A.* 117, 29–36. doi:10.1073/pnas.1908513117

Zhou, Y., Zhang, J., and Hu, S. (2021). Regression Analysis and Driving Force Model Building of CO_2 Emissions in China. *Sci. Rep.* 11, 1–14. doi:10.1038/s41598-021-86183-5

Tiwari, A. (2011). Tourism, Exports and FDI as a Means of Growth: Evidence from four Asian Countries. *Rom. Econ. J.* 14 (40), 131–151.

Mahjabeen, N. (2020). Renewable Energy, Institutional Stability, Environment and Economic Growth Nexus of D-8 Countries. *Mendeley Data* 29 (1), 1–10. doi:10.17632/y6tdzbn9cf.1

Venkatraja, B. (2020). Does Renewable Energy Affect Economic Growth? Evidence From Panel Data Estimation of BRIC Countries. *Int. J. Sustain. Dev. World Ecol.* 27 (2), 107–113. doi:10.1080/13504509.2019.1679274

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