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Original scientific paper

Research on the Path of Energy Economy Transformation under the Goal of Carbon Neutrality

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Abstract: Considering the urgent global issues brought out by climate change, several countries have made "carbon neutrality" the centerpiece of national policies, aiming for a world free of carbon emissions. Environmental laws (R.L.) and breakthroughs in renewable energy technology (RET) are essential to achieving carbon neutrality goals, which are central to this transition. Using pane figures from 30 Chinese provinces between 1998 and 2020, this research adopts a spatial E-Model to explore the interrelated effects of R.I. and RET on green sustainability. It also makes use of theoretical frameworks and empirical data. The results show that if R.I. may not directly improve the local and surrounding environmental quality, it helps reduce CO_2 emissions, especially when economic growth is above the key threshold of 9.126, shown by an "inverted U-shaped" connection in the curve. On the other hand, although RET positively impacts the environment, its effectiveness in reducing carbon emissions decreases if economic growth is above the 8.790 threshold. As a result, the research highlights the dependence of R.I. and RET's carbon reduction benefits on area, underscoring the need for a sophisticated policy strategy that considers economic development levels. This study aims to help policymakers develop comprehensive plans for promoting environmental sustainability, especially within the specific circumstances of the Chinese area.

Keywords: carbon neutrality; climate change; economic growth; energy economy; environmental sustainability

1 INTRODUCTION

This study explores the revolutionary trajectory of energy economies in the quest to minimize the catastrophic implications of global climate change, with the ambitious goal of reaching carbon neutrality. The research threads through the complex processes of energy system development as countries throughout the globe increasingly commit to initiatives targeted at lowering carbon footprints [1]. The study takes a multifaceted approach, emphasizing comprehending the potential and difficulties of this significant shift. By examining the complex interactions between regulatory frameworks, technology advancements, and socioeconomic factors, the study seeks to identify the best paths for energy economies to take to achieve carbon neutrality. In addition to the body of knowledge on sustainable energy transitions, this research provides valuable information that communities, businesses, and policymakers can use to navigate the challenging landscape of energy transformation better while working towards the goal of becoming carbon neutral [2].

Global worries about climate change, environmental degradation, and energy depletion are increasingly pressing, pushing green sustainability to the top of national agendas everywhere. The demands for human development have increased dramatically since industrialization began, and greenhouse gas emissions have been rising steadily at the same time. Research dating back to the 1800s indicates a notable increase in CO_2 levels during the Industrial Revolution [3]. CO_2 is a significant factor in the greenhouse effect and is strongly linked to climate change. A problem not exclusive to China, environmental pollution threatens the ecological balance amid economic growth against globalization. China has seen tremendous economic progress, but the country's environment is rapidly deteriorating due to the spike in resource demand. This calls for urgent governmental interventions to address air, water, and soil pollution, which poses significant hazards to human health and output [4].

Due to the widespread release of greenhouse gases, mainly CO_2, there are difficulties with living quality and regional economic development worldwide. According to a recent assessment by the International Energy Agency, the world's carbon emissions (C.E.) are expected to surpass 36.3 billion tons in 2021, the 6% rise from the record high of 2020 caused by harsh weather and increased energy use. China, the greatest developing nation, overtook the U.S. in 2007 to take the top rank internationally with a total C.E. of more than 6.99 billion tons. However, this impressive economic expansion has a price [5]. China's decline to 160th place in the Environmental Performance Index indicates the severe ecological strain brought on by the country's fast development. In response, to meet the difficulties of "adjusting structure", "promoting transformation", "preventing pollution" and "reducing emissions", the Chinese government has given priority to advances in (RET) and environmental regulation (R.I.) [6].

The Chinese government must quickly negotiate the intricate relationship between environmental protection and economic growth against the background of growing globalization. China's plan for green and sustainable development includes measures like "adjusting structure", "promoting transformation", "preventing pollution" and "reducing emissions". This research examines the impact of (RET) on the decrease of carbon emissions (C.E.) and the efficacy of present environmental laws (R.I.) in achieving this goal [7]. The complex interplay between E.R. and RET and their joint outcome on C.E. reduction must be considered for national climate change policies, development support systems, and low-carbon projects. By elucidating these processes, the study seeks meaningful insights that may direct global cooperation on C.E. reduction technologies and serve as a vital point of reference for achieving carbon neutrality goals.

This study contributes substantially to the current conversation on transforming the energy sector to be carbon neutral. Through a methodical examination of the many processes involved in this transformational journey, the research reveals essential findings with broad implications for communities, businesses, and politicians.

The multifaceted study that considers governmental frameworks, socioeconomic issues, and technological breakthroughs offers a thorough grasp of the potential and problems associated with the goal of carbon neutrality. The results of this study contribute to scholarly discourse and provide helpful advice for interested parties negotiating the challenges related to sustainable energy transitions [8]. The study offers decision-makers essential information to form laws, encourage innovations, and guide societal practices toward a more sustainable and carbon-neutral future by illuminating viable tactics and possible pitfalls.

2 LITERATURE REVIEW

2.1 The Connection between CO_2 Emissions and Green Regulations

The unrelenting push of industrialization and urbanization has brought about an age when the amount and intensity of contaminating gases are increasing. Due to the abrupt and severe changes in the situation caused by this surge, mainly caused by greenhouse gases and CO_2, the human ecology is seriously threatened. As a crucial response to the growing environmental pollution challenge, (R.I.) has drawn more attention from professionals and academics in recent years. It has also emerged as a keystone for achieving sustainable economic and social growth. Two main ideas at the center of the current discussion about the relationship between R.I. and C.E. are the "green paradox" and the concept of "forced emission reduction". The "green paradox" camp claims that R.I. has a negative "regressive effect" on C.E., while the "forced emission reduction" camp claims that R.I. has a beneficial "anti-driving effect [9]. To further elucidate this debate, researchers have examined a variety of dimensions. One such example is shown as ref. [10]. Whose study examines the overall effectiveness of feedback mechanisms in environmental climate policies, revealing the complex dynamics of the "lag effect" and "backfire effect" present in existing policy instruments? Furthermore, a more detailed analysis by other researchers shows an inverse "U-shaped" curve in the trajectory of R.I.'s influence on C.E., indicating a "green paradox" effect that comes before a critical point and is followed by an "emission reduction effect." Spatial studies significantly advance this knowledge by revealing substantial variability between R.I. and C.E. across various national, regional, and urban settings [11]. This regional heterogeneity highlights how the impacts of R.I. on C.E. vary in intensity across various contexts, with developing nations (areas) feeling the consequences more strongly than designed and less developed regions

2.2 The Connection between CO_2 Emissions and Technological Innovation

A comprehensive strategy beyond market processes is required due to the tremendous challenge provided by the externalities of (C.E.) and the civic supplies aspect of the atmosphere. (R.I.) is a powerful tool for addressing environmental issues and market imperfections. However, sustained dedication to technical advancement, particularly innovation focused on green technologies, becomes essential for a long-term solution to the carbon emission crisis. However, the scientific community struggles with differing results and interpretations about how technological progress affects the effect of CO_2 emissions. Prominent research demonstrates this variety. For example, a study on using Best Available Technology (BAT) to control emissions from coke plants under the E.U. Industrial Emissions Directive (IED) indicates a significant decrease in C.E. However, research conducted in Mexico comes to the opposite conclusion, supporting the environmental Kuznets curve (EKC) theory that technological innovation (T.I.) tends to reduce C.E. Research that examined how environmental technology innovation affected local C.E. in Chinese regions found that E.T. innovation may successfully lower local C.E. in several ways. Another research that evaluates the innovations in countries under the Belt and Road Initiative (BRI) on C.E. confirms the beneficial effects of efficient T.I. and suggests that effective T.I. helps reduce C.E. from economic activities or industrial processes. Dissident viewpoints, however, indicate that the C.E. effect of T.I. has a temporal lag and geographical variability, particularly in highly developed locations where T.I. may have little influence on CO_2 pollution in contrast to more significant reductions in impoverished regions. Contrary to popular belief, research looking at the cyclical impact of sustainable and green technology on C.E. in the BRICS nations finds a counter-cyclical relationship in the outset [12]. A spatial econometric model that examines the effects of green technology innovation in Chinese cities highlights the complementary function of technological innovation (T.I.) in green technology, boosting C.E. efficiency within a city while having a suppressive effect in nearby cities. Given these contradictory results, the bidirectional dynamic relationship between T.I. and C.E. raises a vital query [13].

2.3 The Connection between Technical Innovation and Environmental Control

As environmental contamination has become more severe, some claim that R.I. has a "crowding-out effect" on T.I. production, others contend that R.I. has a beneficial influence on T.I. efficiency and considerably contributes to T.I. creation. A more widely accepted current agreement among scholars is that there is no linear correlation between T.I. efficiency and R.I. intensity [14]. A fixed-effects model, for example, that looks at the connection between T.I. Chinese industrial enterprises show a "U-shaped" relationship that initially decreases and increases. Similar findings are reached using a dynamic spatial panel model. However, counterarguments imply a subtle and complicated dynamic, implying an inverted "U-shaped" curvilinear link between R.I. and enterprises' green technology innovation. A "U-shaped" curve of R.I. intensity on T.I. efficiency is shown by research focusing on the Chinese coal-fired power sector from 2008 to 2017 and offering a mediating effects model.

To summarize, the extant literature has thoroughly discussed the relationship between R.I., T.I., and (C.E.), focusing on green technology innovation. However, there is a noticeable lack of research on the impact of energy technology innovation, particularly Renewable Energy Technologies (RET), on corporate competitiveness within the framework of environmental legislation. To achieve "carbon peaking" and "carbon neutrality" on a worldwide scale, as well as to reduce carbon emissions, it is crucial to promote renewable energy [15].

For this reason, studying C.E. from RET is essential. The spatially diverse effects of CO_2 are largely ignored in most research despite the extensive corpus of work on C.E. from R.I. and T.I. This work fills these gaps in the literature and offers a sophisticated comprehension of the complex dynamics involved, thereby making it a helpful addition.

3 DATA, MATERIALS, AND METHODOLOGY

3.1 Theoretical Background

As countries worldwide face the consequences of climate change, the quest for carbon neutrality has taken on an urgency of its own. Environmental economics, sustainable development, and energy policy are the main theoretical frameworks that support studies on achieving carbon neutrality by transforming the energy sector. The idea that conventional energy sources, which produce a lot of carbon dioxide, must be either completely phased out or drastically reduced to reach carbon neutrality is fundamental to this study. Commonly used in carbon emission research, the Environmental Kuznets Curve (EKC) hypothesis suggests a U-shaped link between economic progress and environmental deterioration, but inverted. According to this hypothesis, the ecological effect is said to increase initially as economies progress but then improve when cleaner technology and regulations are adopted. The EKC theory can potentially enlighten conversations about the evolution of carbon emissions at various points in time within the framework of the transition of the energy economy [16].

Switching to renewable energy sources, including solar, wind, nuclear, and hydropower, is essential to reach carbon neutrality. The "Triple Bottom Line" hypothesis provides a framework for evaluating the long-term viability of energy options by considering economic, social, and environmental factors simultaneously. The Energy Transition Theory also stresses diversifying and reducing dependence on fossil fuels. Policy frameworks and global collaboration are vital to the transition to an energy economy. Collaborative efforts are necessary to control global temperature increases, as highlighted by the historic Paris Agreement. The influence of policy and regulatory frameworks on the spread of renewable energy sources may be better understood with the use of Institutional Theory [17]. Theoretical underpinnings like these help countries transform their energy economies and make sense of how economic, environmental, and social concerns interact. They direct studies toward solutions that might get them to carbon neutrality.

3.2 An Economic Model of Spatial Spillover

The STIRPAT model is intended to clarify the elements driving the greenhouse effect. Building on this framework, we extend the STIRPAT model by adding C.E., RI, RET, PGDP, U.R., NFP, and ISU to the research framework [18], by the methods described. The entire regression equation that is produced has the following structure:

$$CE = f(RI, RET, PGDP, UR, NFP, ISU) \tag{1}$$

Taking logs on both sides,

$$\begin{aligned}\ln CE_{it} &= \beta_0 + \beta_1 \ln RI_{it} + \beta_2 \ln RET_{it} + \\ &+ \beta_3\, PGDP_{it} + \beta_4 UR_{it} + \beta_5 \ln NFP_{it} + \beta_6 ISU_{it} + \varepsilon_{it}\end{aligned} \tag{2}$$

A regression model in logarithmic form is supplied in the Equation to analyze China's per capita Carbon Emissions (ln. C.E.). The elements consist of the following: per capita Gross Domestic Product (PGDP), urbanization (U.R.), non-fossil Energy Consumption (ln. NFP), industrial structure (ISU), natural logarithms of Research and Innovation (ln. R.I.), renewable energy technologies (ln. RET), and an error term (ε) [19]. The coefficients represent the projected influence of each variable on per capita carbon emissions (β) associated with it. The link between these variables and carbon emissions may be thoroughly investigated using this Equation, which sheds light on the motivations for environmental sustainability in China's growth.

As has been noted in earlier studies [20]. The continued development of global economic integration indicates that the socioeconomic makeup of surrounding areas and a region's wealth and economic activity influence how well-adjusted its environment is. To account for the complex geographical dependency of Carbon Emissions (C.E.) in various locations, this research makes use of three different spatial econometric models: the geographical Durbin (SDM), Spatial Error (SEM), and Spatial Autoregressive (SAR) models. A more complex understanding of the connections between areas and C.E. is made possible by the distinct insights into spatial interconnections that each model provides.

$$\begin{aligned}\ln CE_{it} &= \beta_1 \ln RI_{it} + \beta_2 \ln RET_{it} + \beta_3 \ln Pgdp_{it} + \\ &+ \beta_4 \ln UR_{it} + \beta_5 \ln NFP_{it} + \beta_6 \ln ISU_{it} + u_i + \varepsilon_{it}\end{aligned} \tag{3}$$

$$\begin{aligned}\ln CE_{it} &= \beta_1 \ln RI_{it} + \beta_2 \ln RET_{it} + \beta_3 \ln Pgdp_{it} + \\ &+ \beta_4 \ln UR_{it} + \beta_5 \ln NFP_{it} + \beta_6 \ln ISU_{it} + u_i + \varepsilon_{it}, \varepsilon_{it} = \\ &\lambda \sum_{j=1}^{n} W_{ij} \varepsilon_{it} + v_{it}\end{aligned} \tag{4}$$

$$\begin{aligned}\ln CE_{it} &= \rho \sum_{j=1}^{n} W_{ij} \ln CE_{it} + \beta_1 \ln RI_{it} + \beta_2 \ln RET_{it} + \\ &+ \beta_3 \ln Pgdp_{it} + \beta_4 \ln UR_{it} + \beta_5 \ln NFP_{it} + \beta_6 \ln ISU_{it} + \\ &+ u_i + v_{it}, v_{it} = \lambda \sum_{j=1}^{n} W_{ij} \varepsilon_{it} + \varepsilon_{it}\end{aligned} \tag{5}$$

$$\begin{aligned}\ln CE_{it} &= \alpha_i + \rho \sum_{j=1}^{n} W_{ij} \ln CE_{it} + \beta_1 \ln CE_{it} + \\ &+ \beta X_{it} + \gamma_1 W \times \ln CE_{it} + \gamma \sum_{j=1}^{n} W_{ij} X_{it} + \varepsilon_{it}, \varepsilon_{it} = \\ &\lambda W v_{it} + \varepsilon_{it}\end{aligned} \tag{6}$$

The above formulas show many types of spatial econometric models that may be used to study the variables that affect Carbon Emissions (C.E.) over time in a particular area (the time dimension is indicated by the subscript "it"). A fundamental panel data model is shown in Eq. (3), which includes variables such as Non-Fossil Power (NFP), Urbanization (U.R.), Research and Innovation (R.I.), Renewable Energy Technology (RET), Gross Domestic Product (PGDP), and Industrial Structure (ISU). The spatial lag model, introduced in Eq. (4), includes a geographically lagged dependent variable that represents the possible impact of nearby areas on C.E. [21]. Eq. (5) includes a geographic error model by considering the error term's spatial autocorrelation. Lastly, Eq. (6) shows a complete model that considers the geographical lag of the dependent variable and exogenous factors X_{it}, with fixed effects (α_i) for specific areas. These models try to represent the many spatial interactions that affect C.E. in different geographical regions.

$$\sum_{j=1}^{n} W_{ij} = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & & & \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix} \tag{7}$$

The spatial weight matrix (W) is represented in matrix form by Eq. (7), where each member w_{ij} indicates the spatial weight between regions i and j. Given that the matrix is symmetric, the impact that region i has on region j and the influence that region j has on part i are equal. The spatial connections or distances among areas may be represented by the components w_{ij} in various ways. To account for the geographical dependency in the study of Carbon Emissions (C.E.) across regions, this weight matrix is an essential part of spatial econometric models since it represents the spatial interactions across various areas.

3.3 Sources of Data and Variables

3.3.1 Variable Explained

This study's methodology for calculating CO_2 emissions (C.E.) is based on accepted practices, with inspiration from previously published research [22]. The research uses a technique in agreement with the 2006 IPCC countrywide Conservatory Gas Guidelines, as official C.E. data for Chinese provinces, municipalities, and independent regions are unavailable at the regional level. To maintain consistency, the end-use energy consumption must be converted into standard coal units using a discount factor. Energy consumption is represented in tons of typical petroleum via this conversion procedure, and the following computation of C.E. is based on a specific formula designed for precise and consistent evaluations. This methodical technique guarantees a constant and trustworthy estimate of carbon emissions in various geographical areas.

$$CE = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} E_i \times NCV_i \times CEF_i \times \frac{44}{12} \tag{8}$$

3.3.2 Essential Explanatory Factors

Environmental regulation (E.R.) significantly impacts several business operations factors, such as labor intensity, capital investment, resource allocation, industrial processes, and technological innovation. Consequently, these modifications have a domino effect on environmental and biological elements. The measuring strategy suggested by ref. [23], is used in this research to assess the impact of environmental legislation. The method of measuring includes the linear normalization of emissions of pollutants, with a particular focus on pollutants including soot, wastewater, and SO_2. By establishing a uniform framework for analyzing the environmental impact of legislation, this normalization process seeks to provide a common foundation for assessing the efficacy of environmental measures. Detailed knowledge of the effects of the regulatory environment on ecological parameters at the regional level is made possible by linear normalization, which makes it easier to conduct a thorough examination of the emissions data.

$$US_{ij}^{s} = \left(\left[\left(UE\right)\_ij - \min\left(\left(UE\right)\_j\right)\right]\right) / \left(\left[\max\left(\left(UE\right)\_j\right) - \min\left(\left(UE\right)\_j\right)\right]\right) \tag{9}$$

In addition, an adjustment factor is included to account for the notable variability in pollutant characteristics across provinces concerning emissions and emission intensity. The adjustment factor must be calculated to normalize the different features of the emissions of pollutants in other areas. The method used to compute this adjustment factor is intended to account for the subtle variations and guarantee a more precise portrayal of the environmental effect. This stage improves measurement accuracy, allowing for a more thorough examination of how environmental regulations affect pollutant emissions in various geographic locations.

$$W_j = UE_{ij} / \overline{UE}_{ij} \tag{10}$$

Lastly, we use the weighting approach to determine the severity of E.R. in each province.

$$ER_i = \frac{1}{3} \sum_{j=1}^{3} W_j UE_{ij}^{s} \tag{11}$$

Innovation in Renewable Energy Technology (RET) is essential to promoting sustainable development and reducing carbon emissions. Based on the endogenous economic growth hypothesis, this study suggests that businesses spend more on R&D as economies expand, which spurs innovation in renewable energy technology. This draws in talent and makes it easier for new technical information to spread, which speeds up the creation of clean technologies and optimizes industrial processes [24]. Carbon emissions are reduced due to RET's contribution to the shift to cleaner energy structures, improved carbon productivity in production processes, and facilitated decarburization of industrial structures. The study evaluates RET using various criteria, such as the number of patents about wind, solar photovoltaics (P.V.), ocean energy, and renewable energy sources. The achievement of carbon neutrality is the aim, which is higher levels of RET are linked to lower carbon emissions.

3.3.3 Regulating Factors

Environmental sustainability goes beyond research and innovation (R.I.) and renewable energy technology (RET). It is a complex idea that is impacted by many different elements. This research includes several control variables to take into consideration additional factors that might have an impact on the outcomes. First, GDP per capita is used as a proxy for regional disparities in economic development to determine the Economic Development Level (PGDP). Another vital aspect is urbanization (U.R.), which reflects changes in population and technological developments, the use of cleaner energy, and the rationalization of lifestyle choices. In this case, a measure is the urban population ratio. Non-Fossil Fuel Power (NFP) operations also have an important role in increasing carbon emissions in a globalized setting. This research uses the GDP's production value from secondary industries as a proxy for the percentage of businesses that use fossil fuels [25].

Finally, Industrial Structure Upgrading (ISU) focuses on improving regional industrial structures by rationally allocating and replacing sectors in response to changes in resource factor endowment. A more extensive index denotes a more optimal industrial design. The research calculates this by comparing the value contributed to the secondary and tertiary industries. These control variables provide a thorough knowledge of the impacts on environmental sustainability while assisting in mitigating possible biases.

3.3.4 Sources of Information and Descriptive Statistics

Panel data from thirty Chinese provinces, directly managed municipalities, and autonomous areas between 1998 and 2020 are used in this analysis. Data for Tibet, Hong Kong, Macau, Taiwan, and Macau are unavailable. Given tables present descriptive statistics and show positive mean values for all variables save R.I. Tab. 1 includes a detailed list and explanation of the chosen variables. At the 5% significance level, the Jarque-Bera test verifies the normal distribution, and the VIF test shows no problems with multicollinearity since all variance expansion coefficients fall below the empirical requirement of 10.

Table 1 The indicator connected to China's CO_2 emission

Element	Feature
Liveliness	TEC, CCP, E.I., NFC, FFP, E.C., TPP
Humanity	T.P., U.R., O.L., RI, VIF
Financial system	GDP, PGDP, SSP, FAI, TSP

Key CO_2 emissions metrics for China are shown in (Tab. 1) which is divided into three sections. The elements that make up "liveliness" include TEC, CCP, E.I., NFC, FFP, E.C., and TPP. The "financial system" aspect includes GDP, PGDP, SSP, FAI, and TSP; the "humanity" element includes T.P., U.R., O.L., RI, and VIF. These metrics provide light on several factors affecting China's carbon dioxide emissions.

Tab. 2 offers a comprehensive list of variables utilized in this paper, along with explanations and symbols correlating to each one. The metric tons of CO_2 emissions per person are represented by the dependent Variable, CO_2 Emissions (C.E.). The ratio of total industrial production to absolute wastewater discharge, the proportion of SO_2 emission relative to total engineering output, and the utilization rate of integrated engineering rock-hard waste are the independent variables associated with Research and Innovation (R.I.). The number of patents about renewable force, wind power-specific patents, solar photovoltaic patents, and marine force patents are among the various independent factors that comprise Renewable Energy Innovation (RET) [26]. Control variables are also considered, including Financial Growth (PGDP), Urbanization (U.R.), Non-Fossil Power (NFP), and Industrial Structure Upgrade (ISU). This provides a thorough framework for analyzing the intricate interactions between variables that affect carbon emissions.

Table 2 Catalog of variables, description, and symbols

Var. type	Var.	Symbol.	Def.
Reliant var.	CO_2 output	C.E.	Metric tons of CO_2 emissions per person
Autonomous var.	Research and Innovation	R I	ratio of entire industrial production to total wastewater discharge
			Emissions of SO_2 as a percentage of total industrial output
			Utilization rate of integrated industrial solid waste
	Innovation in renewable energy technologies	R E T	digit of RE- patent
			The number of patents for storm control
			Patents on lunar photograph voltaic
			patent on Marine force
Control variables	financial growth	P G D P	GDP total divided by population
	Urbanization	U R	percentage of the whole population
	Non-Fossil Power	N F P	% of G D P
	percentage of the whole population	I S U	the ratio of lesser sector extra value to tertiary sector additional value

Descriptive statistics and correlation analysis for the study's significant variables are shown in (Tab. 3). The distribution and properties of the data are guided by the mean and median values and variability metrics, including skewness, kurtosis, standard deviation, and Jarque-Bera statistics. Correlation coefficients show the links among variables, which are included in Tab. 3. The logarithms of carbon emissions (Ln C.E.) research and innovation (Ln RI) and renewable energy technologies (Ln RET) show negative correlations, for example, indicating possible interdependencies. The correlation matrix also shows essential relationships between variables, which helps to clarify how their interdependent dynamics work [27]. The Variance Inflation Factor (VIF) values, often within acceptable levels, show the degree of multicollinearity. In the research context, the observed relationships and coefficients highlight the complicated processes impacting carbon emissions.

Table 3 Descriptive variable statistics and correlation analysis

Var	Ln CE	Ln RI	Ln RET	Ln. PGDP	Ln UR	Ln NFP	Ln ISU
Mean.	−1.169	6.633	10.085	3.806	3.628	4.615	1.97
Med.	−1.087	6.619	10.232	3.832	3.634	4.596	1.921
Maxi	1.282	11.166	12.719	4.495	4.639	6.272	4.282
Mini.	−4.724	0	7.761	2.682	2.271	3.183	0.136
s.dev	0.916	2.02	0.958	0.365	0.305	0.454	0.713
Skew.	−0.434	−0.052	−0.094	−0.272	−0.214	0.325	0.33
Kurt.	3.66	2.461	2.312	2.622	6.134	5.531	3.239
Jaurq-Bera.	34.169 (0.000)	8.662 (0.013)	14.616 (0.001)	12.617 (0.002)	28.758 (0.000)	19.640 (0.000)	14.144 (0.001)
Observe.	691	691	691	691	691	691	691
connection medium							
C.E.							1
RI	1						0.161***
RET	−0.394***	1					0.121***
PGDP	−0.490***	0.801***	1				0.358***
U.R.	−0.241***	0.595***	0.736***	1			0.403***
NFP	−0.145***	0.219***	0.222***	0.255***	1		−0.001
ISU	0.06	0.280***	0.176***	0.293***	−0.357***	1	0.152***
VIF	1.321	3.038	4.623	1.513	2.629	1.879	1.927

Notes: significance at the 1% level is indicated by the symbol; p-values are provided in parenthesis

4 RESULTS AND DISCUSSION

4.1 Test for Spatial Autocorrelation

To evaluate the geographical linkages and dependencies among variable indicators, spatial autocorrelation analysis must be done before performing spatial econometric tests. Ensuring the precision, authenticity, and dependability of the ensuing test findings is contingent upon this. This research uses Moran's I index to assess the autocorrelation of C.E., RI, and RET by ref. [28]. Based on the geographic proximity matrix for 30 Chinese provinces from 1998 to 2020, the local Moran's approximation in Tab. 4 shows positive values at meaning levels of 1%, 5%, and 10%. Fascinatingly, RET has a tiny fall with time as the geographical (spatial) association becomes more muscular. This suggests a considerable geographical dependency in the spatial distribution of Chinese C.E., RI, and RET rather than being completely random. Distinct aggregation patterns - high-high (H-H), low-high (L.H), low-low (L.L), and high-low (H.L) are revealed by analyzing these plots, and they demonstrate spatial autocorrelation across most Chinese provinces throughout the given years.

Using a regional adjacency matrix (Tab. 4) displays data on Moran's catalog, emphasizing different metrics in China over the years. Two of the indicators are renewable investment and renewable energy transition. At the same time, the other is carbon dioxide emissions, abbreviated as C.E. For every indication, this paper includes the year's values and the matching Moran Price and Z Price. Concerning sustainable development, Tab. 4 shows current tendencies, and regional variations, which contributes factors, focuses on energy and water resource limitations. The spatial autocorrelation and clustering patterns of the above indicators over the provided period can be understood by examining the positive and negative values of Moran Price and Z Price, respectively.

Table 4 Moran catalog based on geographic adjacency matrix

Year	Co_2 (C.E.)		(RI)		(RET)	
	Mor. Price	z price	Mor. Price	z price	Mor. price	z price
1998	0.011	0.393	0.041	0.626	0.364	3.408
1999	0.064	0.816	0.029	0.52	0.42	3.83
2000	0.03	0.554	0.067	0.831	0.087	0.992
2001	0.097	1.131	−0.025	0.08	0.147	1.469
2002	0.214	2.037	−0.032	0.017	0.143	1.44
2003	0.054	0.721	0.062	0.785	0.134	1.371
2004	0.394	3.459	0.035	0.561	0.127	1.322
2005	0.06	0.762	0.122	1.263	0.133	1.372

Year	Co_2 (C.E.)		(RI)		(RET)	
	Mor. Price	z price	Mor. Price	z price	Mor. price	z price
2006	0.138	1.407	0.109	1.159	0.356	3.152
2007	0.169	1.661	0.13	1.325	0.471	4.078
2008	0.189	1.825	0.129	1.321	0.504	4.34
2009	0.251	2.328	0.171	1.659	0.488	4.211
2010	0.119	1.253	0.178	1.722	0.489	4.226
2011	0.101	1.095	0.184	1.767	0.449	3.92
2012	−0.009	0.207	0.199	1.894	0.474	4.116
2013	0.129	1.326	0.218	2.047	0.507	4.357
2014	0.157	1.583	0.216	2.027	0.495	4.273
2015	0.09	1.021	0.217	2.025	0.477	4.12
2016	0.162	1.623	0.233	2.149	0.429	3.74
2017	0.105	1.128	0.213	1.997	0.416	3.634
2018	0.122	1.268	0.248	2.268	0.406	3.562
2019	0.107	1.163	0.242	2.22	0.401	3.536
2020	0.042	0.625	0.275	2.486	0.348	3.109

Note: the coefficient of the variable has been selected to use a meaning test of 1%, 5%, and 10%, correspondingly

4.2 Examination and Selection of Spatial Measurement Models

Considering the variety of spatial econometric models, this investigation methodically utilizes the L M, Wald, and L R tests to resolve the most appropriate spatial model before proceeding with model estimation [29]. As a result, the spatial structural equation model (SEM) is deemed a more appropriate selection than the spatial autoregressive model (SAR). In addition, at the 5% confidence level, the initial hypotheses of the Wald and LR tests are rejected.

Table 5 Spatial form trial outcome

Trial	Index	Statistics	P value
L M trial	L M cover trial	7.738	1.008
	R-L M cover trial	4.036	1.082
	L M-error trial	6.591	0.017
	R-LM-error trial	2.887	0.168
Wald trial	Wald S A R	88.16	1.001
	Wald S E M	62.62	0.001
L R trial	L R S A R	24.53	1.025
	LR SEM	27.46	0.007

Note: the coefficient of the variable has been selected to use a meaning test of 1%, 5%, and 10%, correspondingly

Results from spatial form experiments are shown in (Tab. 5), which includes several scenarios and the associated statistical metrics. An index of 7.738 and a significant p-value of 1.008 indicate a substantial difference between the "L M trial" and the "L M cover trial." Similarly, there is a notable difference in the "R-L M cover trial," where the index is 4.036 and the p-value is 1.082. The "L M-error trial" stands out for having a significant difference, with a p-value of 0.017 and an index of 6.591. On the other hand, the "R-LM-error trial" yields a p-value of 0.168 and an index of 2.887, indicating a less significant but still noteworthy result. The Wald trial" highlights significance even more, especially in "Wald S A R" with a p-value of and an index of 88.16.

4.3 Benchmark Outcomes

The findings illustrate a discernible "forced emission reduction" effect in conjunction with a heightened intensity of R.I., which has not had a detrimental impact on the present state of regional economic progress in China. Nevertheless, the findings also reveal a notable adverse impact of RET and Non-Financial Performance (NFP) on C.E. More precisely, the 1% growth in RET and NFP would result in a corresponding decrease of 0.115% and 0.064% in C.E. This implies that the rise in RET and industrialization contribute in a positive way to the enhancement of environmental quality. However, at the 10% significance level, NFP is statistically insignificant, suggesting that the development of regional industrialization has a minimal effect on the reduction of C.E. In contrast, prior investigations concerning the BRICS countries and China reached the conclusion that green RET facilitates C.E. advancement without detrimentally impacting economic development, specifically in underdeveloped areas. Enhanced economic levels, such as urbanization, fossil fuel power, and industrial structure modernization, foster Environmental Technology (E.T.) innovation, specifically in the realm of green and clean RET, as R.I. intensifies. By doing so, the efficacy of regional industrial production in China is improved, and the proportion of fossil fuel consumption in urban industrial production is diminished. As a result, the consumption of industrial materials decreases, contributing to the additional reduction in carbon emissions from the industrial sector. Consequently, RI can hurt the efficacy of C.E. via RET, and ultimately, emission reduction targets can be met.

Table 6 Spatial group decay outcome

Var.	mold.1	mold.2	mold.3	mold.4	mold.5	mold.6	mold.7
	F.E	S.E.M	S.A.R	S.D.M	Dir. Result	Ind. result	Sum result
Wx × ln RI			0.085** (2.20)				
Wx × ln RET			−0.171*** (−2.84)				
Ln RI	0.068*** (2.57)	0.788*** (3.26)	0.061** (2.30)	0.078*** (2.82)	0.200*** (3.09)	0.278*** (3.71)	0.171*** (6.12)
Ln RET	−0.121*** (−3.03)	−0.062* (−1.80)	0.128*** (2.64)	0.110** (2.43)	−0.198** (−2.28)	−0.088* (−0.95)	−0.064** (−2.26)
Ln PGDP	0.058 (0.72)	0.039 (0.58)	0.178 (1.35)	0.198* (1.66)	0.085 (0.50)	0.284 (1.75)	0.416*** (6.64)
Ln U.R.	−0.097 (−0.94)	−0.077 (−0.72)	−0.015 (−0.14)	0.035* (0.29)	0.634 (1.59)	0.668** (1.41)	0.387*** (4.09)
Ln NFP	0.521*** (3.67)	0.553*** (4.04)	0.484*** (3.32)	0.542*** (3.52)	0.707 (1.37)	1.249** (2.10)	−0.115* (−1.11)
Ln ISU	0.349*** (3.98)	0.365*** (4.23)	0.387*** (4.11)	0.435*** (4.29)	0.497* (1.45)	0.933** (2.37)	0.286*** (3.55)
Car.							−3.882 (−8.31)
Housman							48.57
Num.	691	691	691				691
Spatial λ/ρ	0.469*** (11.66)	0.461*** (11.72)	0.474*** (18.16)				
σ^2	0.1538*** (18.18)	0.154*** (18.21)	0.150*** (18.16)				

Notes: the coefficient of the variable has been selected to use a meaning test of 1%, 5%, and 10%, correspondingly

The results of spatial group decay are summarized in (Tab. 6) which presents distinct variables from different models. Model 3 shows a significant positive effect for the variable "Wx × ln RI," with a coefficient of 0.085** (2.20). In model 2, however, "Wx × ln RET" exhibits a statistically significant negative influence (coefficient = −0.171*** (–2.84)). From 0.068*** (2.57) to 0.171*** (6.12), the natural logarithm of regional income (Ln RI) exhibits positive and significant coefficients in models 1 through 7. On the other hand, different impacts are shown by the natural logarithm of regional employment (Ln RET), with negative coefficients seen in models 1, 2, and 6. Furthermore, variables like Ln PGDP, Ln U.R., Ln NFP, and Ln ISU reveal different impacts across models, which shed light on these models' spatial group decay dynamics.

4.4 Nonlinear Effect Examination

The effects of green (renewable energy) or regulatory intensity (R.I.) technological innovation on carbon emissions (C.E.) have been the subject of conflicting research in the past; results have ranged from positive to negative or even showed no discernible effect. This research suggests that there might be a correlation between the nonlinear connection between R.I., Renewable Energy Technology (RET), and C.E. and the variability in the degree of sustainability of the regional green economy. The following are essential elements influencing this nonlinear relationship. Higher levels of regional economic growth are associated with a more significant siphoning effect, making R.I. infectious and encouraging imitation across the area: heterogeneity and Regional Variations in RET [30]. Significant geographical variations and variability exist at the RET level. Higher PGDP levels signify a more important regional focus on environmental and economic sustainability to satisfy sustainable development needs, encouraging more investment in technological innovation in green energy (renewable energy). R.I. Intensity's Effects on Industrial Structure: Foreign capital is hampered by the deepening of R.I., which deters the admission of very polluting businesses.

Table 7 Outcome of the entry cause check

entry view		entry rate	entry view	entry rate
breakdown threshold result of ln R.I. on ln CE				
F-value	only	15.99	Ln RI*I (Th < q)	1.235
	dual	41.45		
	triple	21.47	Ln RI*I (Th ≥ q)	−1.348
Threshold	Q	8.125		
Coefficient	Ln RET	1.158	Ln NFP	1.490
	Ln UR	−0.092	Ln ISU	1.401
breakdown threshold result of ln RET on ln CE				
F-value	only	7.32	Ln RET*I (Th <q)	−1.382
	dual	11.10		
	triple	6.33	Ln RET*I (Th ≥q)	−1.187
Threshold	Q	9.791		
Coefficient	Ln RI	1.095	Ln NFP	1.558
	Ln UR	−1.057	Ln ISU	0.408

Note: the coefficient of the variable has been selected to use a significance test of 1%, 5%, and 10%, respectively

(Tab. 7) presents findings from the Threshold Effect Test, examining the impact of thresholds on the relationship between the natural logarithms of cultural spending (ln C.E.) and regional income (Ln RI and Ln RET). Strong F-values in the single, dual, and triple breakdown views (15.99, 41.45, and 21.47, respectively) for the threshold of Ln RI on ln C.E. show a strong threshold impact. The coefficients for Ln RET, Ln U.R., Ln NFP, and Ln ISU under various threshold perspectives provide subtle insights into their involvement in this impact, and the determined threshold value (Q) is 8.125. Similar to this [31], substantial F-values (7.32, 11.10, and 6.33) for the threshold of Ln RET on ln C.E. indicate a threshold effect. A threshold value (Q) of 9.791 has been established. The different threshold perspectives' coefficients for Ln RI, Ln U.R., Ln NFP, and Ln ISU show their unique contributions to the observed threshold effect. These results advance our overall knowledge of how, at various threshold levels, thresholds regulate the linkages between economic factors and cultural spending.

4.5 Creating Scenarios

This study divides influencing elements into three growth scenarios: high, medium, and low. It is guided by the strategic goal outlined in the development plan of the Chinese government and draws insights from credible projections both locally and globally. The medium scenario is a foundational understanding of China's expected socioeconomic environment and has been selected as the central point for variable clarification. Extracted from the medium system, the high and low scenarios represent different aspects of the possible dynamics of China's future development. The Supplementary data contains a detailed description of the parameters that define each method.

They follow the models of previous studies [32]. Moreover, considering the possibility of reaching a carbon-neutral course, this analysis develops nine scenarios. These scenarios assume changes in socioeconomic situations, variances in economic development patterns, and legislation implementation to reduce carbon emissions.

In Tab. 8, S1 provides a detailed description of the parameters for every scenario. The scenarios go through several emphases, beginning with the slowdown scenario (S1), characterized by an economic slump and all indicators at their lowest point. While S3 concentrates on green growth, stressing economic quality and encouraging low-carbon output, S2 represents the overall picture and prioritizes standard economic development. The energy-saving scenario, presented in S4, calls for a halt to large-scale expansion and building together with higher energy consumption expenses. S5, the design of the energy economy transition, emphasizes the modernization of the industrial structure and the application of new energy sources. Next, S6 represents the modest emission reduction scenario, in which development is sluggish due to the dominance of the secondary industry. The intense emission reduction scenario (S7) prioritizes reducing emissions at the expense of slowing down economic growth. S8 moves through the medium emission reduction scenario, characterized by a slow phase of urbanization and upgrades to industrial structures. Finally, S9 depicts a system of intensive industry, marked by quick urbanization but slow industrial upgradient. Every scenario offers a different viewpoint on possible routes to carbon neutrality.

(Tab. 8) lists the limitations corresponding to various scenarios. All the components in Scenario 1 (S1) are modest, suggesting that the situation is generally constrained. For most variables, Scenario 2 (S2) is a medium-level situation. Scenario 3 (S3) indicates a scenario with extensive circumstances due to its high levels across all criteria considered. Scenario 4 (S4) exhibits medium and high levels, particularly in regional employment and net foreign portfolio. High levels of numerous parameters, such as provincial income and venture investment funding, are combined in Scenario 5 (S5). Most of the variables in Scenario 6 (S6) are set low, while the degree of regional employment is high [33]. A combination of medium and high levels is present in Scenario 7 (S7), with high values for variables including venture investment funding and cultural expenditure. There is variation in Scenario 8 (S8), combining medium and low levels in several elements. Lastly, Scenario 9 (S9) has solid values for the Innovation and Start-Up Index, Net Foreign Portfolio, and Urbanization Rate. This Table helps to clarify the constraints related to each scenario by offering an organized summary of how changes in essential parameters determine various situations.

Table 8 Limitation conniving of scenario

Scenario	C.E.	RI	RET	PGDP	UR	NFP	ISU	VIF	CCP
S1	Low	Low	Low	Low	Low	Low	Low	Low	Low
S2	Medium	Medium	Medium	Medium	Medium	Low	Medium	Medium	Medium
S3	High	High	High	High	High	High	High	High	High
S4	Medium	High	Medium	Medium	Medium	High	Low	Low	Low
S5	High	High	High	High	Medium	High	Medium	High	Medium
S6	Low	Low	Low	High	Low	Low	Medium	Low	Medium
S7	Medium	Medium	High	High	High	High	High	Low	High
S8	High	Medium	Medium	Medium	Medium	Low	Low	Medium	Low
S9	High	Low	Low	Low	Medium	Low	High	High	Medium

4.6 An Examination of China's Carbon Neutral Scenarios

Using the suggested model, we ran simulations to forecast how China's carbon emissions would change under several scenarios between 2020 and 2060. The different timetables for reaching peak carbon emissions, which range from 2029 to 2034, demonstrate the accomplishment of emission reduction objectives. Furthermore, there is a significant range in the peak numbers, which vary from 11568.6 to 13224.2 million metric tons. These scenarios can be divided into three groups according to how well they achieve the carbon peak and neutrality goals.

Tab. 9 offers cost estimates for several scenarios that consider variables such as the peak cost per million tons (M ts), impartiality in 2060, and the per million tons of cultural expenditure (C.E.) in 2060. The climax point in Scenario 1 (S1) is anticipated to happen in 2033, with a peak cost of 12998.5 per M ts. The C.E. in 2060 is 7694.6 per M ts. However, impartiality is marked as "NO," suggesting a lack of justice or objectivity. A climax point is estimated for 2034 by Scenario 2 (S2), with a peak cost of 12553.6 per M ts. Fairness is shown by the scenario's "YES" rating for impartiality in 2060, and the C.E. for that year is 2327.5 per M ts [34]. A climax point is predicted for 2029 in Scenario 3 (S3), with a peak cost of 11918.2 per M ts. However, impartiality in 2060 is marked as "NO", and −33.7 per M ts is stated for the C.E. in 2060. The climax point in Scenario 4 (S4) is anticipated in 2031, with a peak cost of 11568.6 per million. In 2060, impartiality is rated as "YES", and the C.E. is estimated at 2495.5 per million ts. A climax point is projected for 2030 in Scenario 5 (S5), with a peak cost of 12330.6 per M ts. The answer for impartiality in 2060 is "YES," the C.E. is estimated to be 499.4 per million times in 2060. Similar details are given in the following scenarios (S6 to S9), which provide a thorough overview of each scenario's estimated expenses and associated characteristics.

Table 9 shows the calculation cost in different scenarios

Scenario	climax point	peak cost / M ts	impartiality in 2060	C.E. in 2060 / M ts
S1	2033	12998.5	NO	7694.6
S2	2034	12553.6	YES	2327.5
S3	2029	11918.2	NO	−33.7
S4	2031	11568.6	YES	2495.5
S5	2030	12330.6	YES	499.4
S6	2033	12493.4	NO	5380.7
S7	2031	12151.3	NO	3167.8
S8	2033	12776.6	NO	7364.3
S9	2032	13224.2	YES	5081.4

4.7 Robustness Examination

Recognizing the spatial weight matrix's sensitivity, this research conducts a comprehensive analysis to improve the validity and consistency of its conclusions [35-38]. In particular, the study reassesses and adopts an economic proximity matrix and geographic proximity moments, the impacts of Renewable Energy Technology (RET) and Regulatory Intensity (R.I.) on Carbon Emissions (C.E.). To do this, the measurements of core variables are adjusted to include the knowledge stock of per capita RET and costs associated with pollution control equipment and emission charge revenues to quantify R.I. intensity (Tab. 10).

The results of a robustness test that looked at how different dimensions and a different freedom mold affected the variables are shown in Tab. 10. When the dimension process is changed for the variable Ln RI, the result is a coefficient of 0.449* (t-statistic: 1.71), with distinct matrices (SDM, G.P, and E.P) contributing coefficients of differing importance. Similarly, the variable Ln RET exhibits sensitivity to changes in dimension, with coefficients under various specifications ranging from -0.157*** to −0.134***. Wx × ln RI and Wx × ln RET, the interaction terms, also show complex reactions to modifications in dimension processes [39, 40]. Significant differences in coefficients across dimension adjustments are displayed by the spatial parameter (Spatial ρ), highlighting the significance of model robustness assessments. Every model consistently includes control variables and the sample size.

Table 10 Robustness test

Var.	Modify dimension process		Replace the freedom mold	
	FE	SDM	G.P Matrix	E.P Matrix
Ln RI	0.449* (1.71)	0.060** (2.23)	0.171*** (6.12)	0.109*** (3.97)
Ln RET	−0.157*** (−3.29)	−0.077*** (−0.87)	−0.064** (−2.26)	−0.134*** (−3.45)
Wx × ln RI	0.078** (2.07)	0.022** (0.35)	0.048* (1.31)	
Wx × ln RET	−0.061* (−1.26)	−0.220** (−2.33)	−0.391*** (−4.19)	
Spatial ρ	0.463*** (11.54)	0.674*** (12.19)	0.654*** (11.12)	
Control	Yes	Yes	Yes	Yes
N	691	691	691	691

Note: significance at the 1% level is indicated by the symbol; p-values are provided in parenthesis'

5 CONCLUSION AND POLICY RECOMMENDATION

Developing a carbon-neutral energy economy is a critical goal in the worldwide fight against climate change. This study explores the complex process of transforming the energy sector to achieve the lofty objective of carbon neutrality. The main findings are as follows. The results clarify many approaches, difficulties, and policy ramifications that influence events leading to a low-carbon and sustainable future. The main pillar of the planned energy revolution is the investigation of renewable energy sources. The report emphasizes the importance of using renewable energy sources like solar, wind, and hydro to replace conventional fossil fuels. From the past work, the reaching carbon neutrality requires a diverse energy mix that includes these renewable sources. However, switching to renewable energy sources necessitates extensive grid upgrades, technical advancement, and infrastructure expenditures. Therefore, policymakers must develop innovative policies that encourage public and commercial sectors to embrace renewable energy technology more quickly. Another essential component of the transformation process is energy efficiency. The study emphasizes how innovative methods and technology may help reduce energy use in various industries. Energy-efficient appliances, smart grids, and improved building insulation significantly reduce energy use. Consumers and companies are encouraged to adopt energy-efficient practices, which become increasingly important as economies change. To promote energy efficiency on a large scale, policymakers must create vital incentive programs, rules, and public awareness campaigns. Although there are encouraging opportunities for future work, the research has several limitations that should be carefully considered.

1. The most significant of them is the unpredictability of the rate of technological adoption. Although renewable energy technologies have much promise,

their broad adoption will rely on several variables, including public acceptability, market dynamics, and scientific advancements. The socioeconomic effects of the energy transition are also problematic, as they might cause disruptions in some businesses and communities. To avoid social injustice and economic inequality, a fair transition considers these issues to be essential. It is necessary to take a sophisticated approach while creating future policies.

2. Policymakers must use a contextualized approach that considers geographical variances, economic inequalities, and distinct populations' obstacles. It is possible that a strategy that suits all situations will not be able to handle the many energy environments worldwide. To create policies that balance environmental stewardship and economic development, policymakers should have in-depth discussions with various stakeholders, including businesses, local communities, and ecological organizations. International cooperation is also crucial to reaching global carbon neutrality. The study promotes international collaboration in sharing resources, technology, and expertise. Collaborative efforts have the potential to quicken the rate of innovation, make it easier for sustainable practices to spread, and give poor countries financial help as they work towards becoming carbon-neutral economies.
3. To address the transboundary aspect of climate change, the cost of transformation is shared among states; it is imperative to establish a robust international framework for collaboration. Considering the future, the research provides information that can guide policy directions. By supporting research and development in clean energy technology, policymakers should concentrate on establishing an atmosphere conducive to innovation. Large-scale investments in workforce development and education are essential to provide the workforce with the skills required for the changing energy market. In addition, it is necessary to build ongoing monitoring and assessment procedures to oversee the advancement of energy transformation projects and modify policies in response to new difficulties.
4. Geopolitics may become the biggest obstacle to global decarbonization. The geopolitical landscape built on fossil fuels itself has become a resistance to energy transformation, and this resistance comes from the fact that advantageous countries in the original landscape will suffer huge losses due to global decarbonization. Furthermore, carbon neutrality cannot eliminate zero sum games. There are three paths through which geopolitics affects carbon neutrality. The existing geopolitics determine a country's basic stance on carbon neutrality, with major fossil fuel powers generally resisting decarbonization, the European Union committed to becoming a global climate leader, and China and India having complex motives. Secondly, the geopolitical situation in the next decade determines whether energy can be transformed or at what rate. The third path that is easily overlooked is to change carbon dioxide emissions. Geopolitical risks have complex impacts on carbon dioxide emissions, and the direction of their effects is still difficult to predict.

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