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Oil prices and the renewable energy transition: Empirical evidence from China

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ABSTRACT

This paper explores the effect of oil price, gross domestic product (GDP), and carbon dioxide (CO2) emissions on renewable energy consumption in China from 1990 to 2020, utilizing the canonical cointegrating regression (CCR) method. The findings indicate that the oil price, GDP and CO2 emissions positively and significantly affect renewable energy consumption over the examined time frame. Numerically, a 1% increase in oil prices, GDP, and CO2 emissions results in a 0.16%, 0.39%, and 1.70% increase in renewable energy consumption, respectively. The positive effect of oil prices on renewable energy consumption can be seen as the cost advantage of renewable energy, which may grow with rising oil prices, leading to a rise in its adoption. The study underscores the significance of promoting renewable energy usage, emphasizing the need for policies that aid energy security and environmental sustainability.

1. Introduction

In today's world, energy is essential for powering economic development. It is essential in all economic activities, as producing goods and services would be impractical otherwise. The availability of sustainable and cost-effective energy significantly influences the economic growth of a nation. Economic growth generally entails the process of industrialization and urbanization, which ultimately results in greater energy consumption. Therefore, the demand for energy in a country increases in tandem with its aggregate output (Sadorsky, 2009). However, the intensive use of energy and natural sources adversely affects the environment, leading to ecosystem degradation. The emissions resulting from burning fossil fuels, particularly the increase in CO2 levels, have irreversible impacts on the environment and atmosphere (Wang et al., 2023; Shahzad et al., 2021; Mukhtarov et al., 2022a). As a result, economic activities that promote development and generate wealth also emit greenhouse gases (GHG), which contribute to environmental damage (Sokolov-Mladenović et al., 2016; Fareed et al., 2021; Mukhtarov et al., 2022b). Moreover, there has been a substantial increase in global carbon emissions. Specifically, global CO_2 emissions have risen by over 60% since 1990 (Statista, 2023). In 2019, it was noted that fossil fuels constituted almost 84% of the world's primary energy (Ritchie and Roser, 2020).

The OECD's latest Global Material Resources Outlook to 2060 reports that fossil fuel-based energy production will remain the primary driver of global GHG emission growth (OECD, 2019; Sadik-Zada and Gatto, 2021). The escalating release of greenhouse gases poses a pivotal environmental challenge, as it is the primary contributor to global warming and environmental harm. Effectively addressing this issue necessitates transitioning towards more ecologically friendly and sustainable energy sources. Numerous studies underscore that attaining a considerable drop in GHG emissions would be exceedingly challenging without a significant uptick in the usage of renewable energy sources (Troster et al., 2018; Mohsin et al., 2021; Liu et al., 2023). In light of this, various global organizations, including the United Nations (UN), the International Energy Agency (IEA), the Organization of Economic Cooperation and Development (OECD), and the International Renewable Energy Agency (IRENA), have committed to substituting conventional energy sources with sources of renewable energy to mitigate detrimental GHG emissions.

The existing body of research indicates that renewable energy is widely considered a viable substitute for crude oil in terms of energy

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consumption and production. From this perspective, there is an anticipated positive connection between oil prices and the demand for renewable energy. The reasoning is that escalating oil prices catalyze businesses and households to curtail their consumption, invest in energy-efficient products, and shift from conventional energy sources to renewable ones. (Omri et al., 2015). In essence, high oil prices should serve as incentives to boost investments in alternative energy. Until the latest sharp decline in oil prices, this hypothesis held. The volatility of oil prices is considered a factor contributing to the increasing attractiveness of renewable energy to lessen dependence on oil, making it susceptible to oil price shocks. Declining this reliance has become a significant challenge for oil-importing countries (Deniz, 2019).

Nevertheless, within the framework of nations that import oil, elevated oil prices deter the utilization of oil products, prompting a shift toward alternative sources. Consequently, this transition may result in a rise in energy consumption from renewable sources. For instance, Deniz (2019) for oil-importing countries, Azad et al. (2014) for Australia, Apergis and Payne (2014a) for 25 OECD countries, Padhan et al. (2020) for OECD members, Nguyen and Kakinaka (2019) for low-and high--income economies, Chen et al. (2021) for less democratic nations revealed oil price positively and significantly affects renewable energy consumption (REC). Therefore, it becomes imperative to conduct country-specific research to ascertain how REC reacts to fluctuations in oil prices. Considering these factors, it is essential to explore whether the volatility in oil prices influences countries to transition from conventional energy consumption to renewables.

Given these factors, examining how oil prices affect the shift to renewable energy in China, a significant contributor to greenhouse gas emissions globally, is worthwhile. Notably, there is a shortage of research focusing on the impact of oil prices on renewable energy consumption in the case of China. This study fills this gap by addressing key questions. First, how does oil price affect renewable energy consumption in China? Second, what role does GDP play in boosting renewable energy consumption in China? Third, how do CO2 emissions influence renewable energy consumption in China? This research aims to thoroughly analyze these factors using the canonical cointegrating regression (CCR) technique, focusing on China. As of 2021, China ranked second worldwide in GDP, calculated in current US dollars. It had the first position in terms of exports and the second position in terms of imports.

Additionally, China stood as the 75th largest economy in the world based on GDP per capita (current US dollars) and was positioned as the 25th highest complex economy based on the Economic Complexity Index (ECI) (OEC, 2021). Moreover, China was positioned second among the top 40 global markets for renewable energy investment and deployment opportunities. This ranking was determined using five criteria: macro fundamentals, energy necessity, policy, project execution, and technology (EY, 2022). These factors make China a unique subject for study.

The current literature lacks research on the relationship between oil prices (OP) and REC in China employing country-specific time series data. Given this gap, this paper aims to address the issue using the CCR approach. The study specifically examines the impact of oil prices, CO2 emissions, and GDP on REC in China. The contributions of this research are twofold: (a) it investigates the influence of economic growth on REC in China, an aspect not explored within an energy–income framework, potentially providing insights applicable to similar economies; (b) as far as our knowledge extends, it is the sole individual time series study that examines the impact of oil prices on REC in the case of China as an oil-importing developing country.

2. Renewable energy in China

China, the greatest emitter of greenhouse gases globally, has been transitioning to become a prominent player in renewable energy. In the last decade, there has been a substantial rise in the focus on green energy to address the worsening environment and maintain economic development. Presently, similar to several other nations that have recently embarked on the path towards low-emission, China's proportion of renewable energy in the overall composition of energy remains very modest. Coal is the primary energy source in the nation, and it is also one of the leading causes of the well-known air pollution problem. China has emerged as a prominent advocate for the expansion of renewable energy worldwide, particularly in the field of solar energy, due to its commitment to public health and sustainable development (Statista, 2024). As shown in Fig. 1, the share of renewable energy in electricity production has increased rapidly over the past decade, reaching approximately 30% by 2022.

From 2019 to 2024, China is projected to contribute 40% of the worldwide increase in renewable energy capacity. This growth will be fueled by advancements in integrating renewable energy systems, reducing the amount of unused energy, and improving the economics of solar photovoltaic and onshore wind technologies. China is projected to contribute about 50% of the worldwide increase in distributed PV (photovoltaic) systems within the same time frame (IEA, 2024b). In 2022, China installed nearly the same amount of solar photovoltaic capacity as the rest of the world. Then, in 2023, it doubled its new solar installations, boosted new wind capacity by 66% and nearly quadrupled its energy storage additions (Hilton, 2024). Therefore, China has allocated substantial resources to developing renewable energy infrastructure in the past decade, including the construction of expansive wind, solar, and hydroelectric power plants in the nation's western region. The objective behind these efforts is to reach the highest level of carbon emissions by the year 2030. The generation of electricity by renewable resources (including hydropower) is demonstrated in Fig. 2. Hydropower has been crucial in China's electricity generation for many years. Over the last decade, wind and solar energy have seen rapid growth. By 2021, renewable energy sources accounted for about 30% of China's electricity production, with hydropower contributing approximately biomass 2%, solar 4%, 16%, and wind 8% (IEA, 2024c).

In addition, the proportion of REC in overall final energy consumption, expressed as a percentage, is illustrated in Fig. 3. From 1990 to 2011, there has been a noticeable decline in the proportion of renewables, dropping from 33.9% to a minimum of 11.3%. The decrease indicates a transition towards energy sources that cannot be replenished within that timeframe, most likely due to industrialization and a greater dependence on fossil fuels. Since 2011, there has been a steady rise, reaching 15.2% by 2021, suggesting a renewed emphasis on renewable energy, maybe motivated by environmental concerns and breakthroughs in renewable technology.

3. Literature review

Researchers have extensively explored the relationship between oil prices(OP) and REC. In this context, we conducted a review of research studying the impact of OP on REC across various economies. Table 1 provides a summary of the results obtained from recent empirical investigations. According to the table, most of these studies observed a positive impact of OP on REC in oil-importing nations.

As indicated in Table 1, a few prior time-series research has explored the impact of oil prices on renewable energy consumption in China. Therefore, this article aims to address this gap by applying the CCR method to examine the long-term effects of oil prices, GDP and CO2 emissions on renewable energy consumption in the case of China. The findings of this study will provide researchers and policymakers with valuable insights for formulating environmental policy recommendations.

4. Functional specification and data

Sadorsky (2009) proposed a functional specification in which renewable energy consumption per capita is modeled as a function of

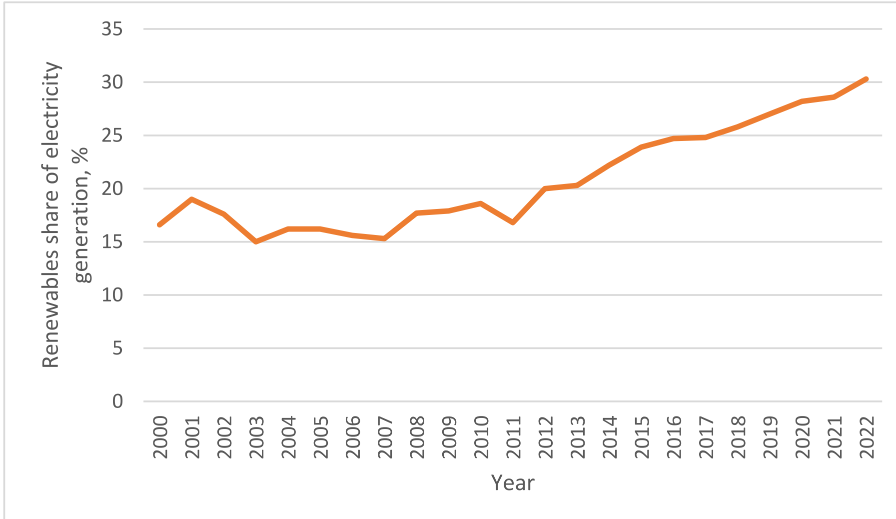

Fig. 1. Renewable proportion of electricity production, %.
Source: IEA, 2024a.

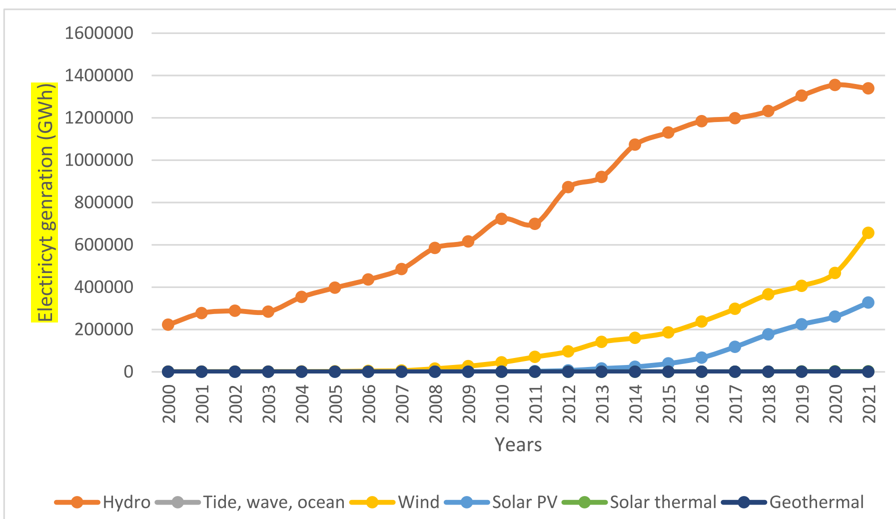

Fig. 2. Production of electricity by renewable resource in GWh.
Source: IEA, 2024a.

real oil prices, real GDP per capita, and carbon dioxide emissions per capita. Building on a similar model specification, Salim and Rafiq (2012) and Apergis and Payne (2015) developed a model where oil prices, real GDP per capita, and CO2 emissions determine renewable energy consumption. In addition, Omri et al. (2015) analyzed the impact of oil price, GDP, CO2 emissions, and trade on REC. Furthermore, several studies have examined the effect of oil prices, real GDP per capita, and CO2 emissions on REC across various countries, including studies by Mukhtarov et al. (2020, 2021), Mukhtarov et al. (2022b), among others. Following the studies mentioned above, the functional specifications in this research can be summarized as follows:

$$ln\ REC_t = \beta_0 + \beta_1\ ln\ OP_t + \beta_2\ ln\ GDP_t + \beta_2\ ln\ CO_{2,t} + \varepsilon_t \quad (1)$$

where, REC_t is renewable energy consumption, OP_t is real oil price, GDP_t is Gross Domestic Product, CO_{2t} is Carbon Dioxide emissions, and εt is an error term.

We conducted this study using annual data for China from 1990 to 2020. Our dependent variable is REC, which denotes the percentage of renewable energy consumption in the aggregate final energy usage. The price of oil (OP) is denominated in US dollars per barrel, with adjustments made for the consumer price index of the United States. Carbon dioxide emissions (CO2) are computed in million tonnes of carbon. GDP is indicated by gross domestic product in US dollars at 2015 prices. OP data is gathered from the Federal Reserve Bank of St. Louis (FRED, 2023). REC, CO2 and GDP data are acquired from the World Bank database (World Bank, 2023). In the estimations, all variables are employed in logarithmic form.

5. Econometric methodology

Before estimating the long-term relationship, we test the variables for non-stationarity using the Augmented Dickey-Fuller (ADF; Dickey and Fuller, 1981) test. Once the variables have been integrated in the same order, the next step will be to test them for a long-term co-movement/cointegration relationship. The Park added variables (Park, 1992) cointegration test was used for testing the cointegration relationship. The long-run impact of independent variables on REC is assessed using Park's canonical cointegrating regression (CCR) method in 1992. Park's

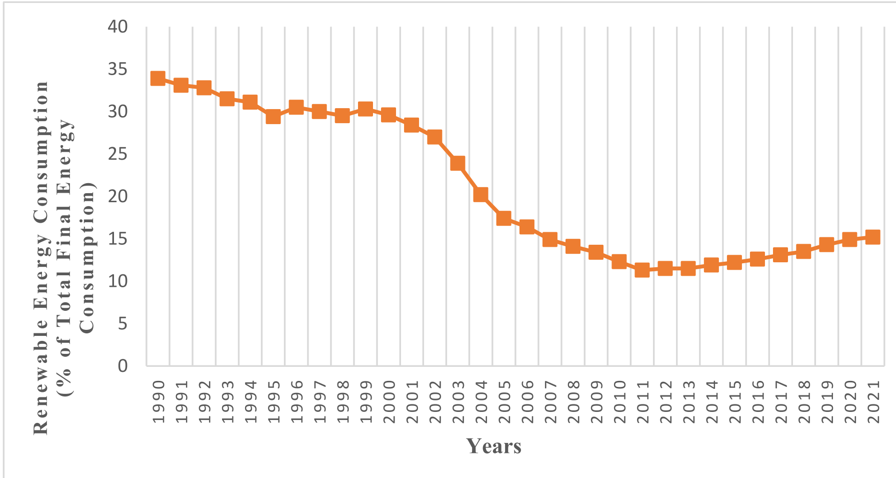

Fig. 3. Percentage of Renewable Energy Consumption in Total final Energy Use, %.
Source: World Bank, 2024.

(1992) canonical cointegrating regression is similar to fully modified ordinary least squares (FMOLS), but it uses stationary transformations of the (Y_{1t}, X_t') data to achieve least squares estimates, aiming to eliminate the long-term dependence between the cointegrating equation and the stochastic regressor innovations. As with FMOLS, CCR estimates adhere to a mixed normal distribution, free from non-scalar nuisance parameters, allowing for asymptotic Chi-square testing (Park, 1992).

The approaches mentioned above have been extensively utilized in previous empirical studies. However, a detailed discussion of these tests is omitted here to avoid overwhelming readers with intricate mathematical explanations and conserve space. Comprehensive information can be found in Dickey and Fuller (1981) and Park (1992).

In addition, Fig. 4 presents a visual representation of the comprehensive approach used in the empirical study, highlighting the key stages or milestones involved.

6. Empirical results and discussions

The variables' unit root problems are initially examined using the ADF unit root test. The outcomes of this test are outlined in Table 2. According to the table, all the variables exhibit non-stationarity at their levels but attain stationarity at the first difference. Consequently, an analysis of their cointegration relationship becomes feasible.

The results of the Park added variables cointegration test are presented in Table 3. The critical value of Chi-Square from the Park test is lower than its critical values, which indicates that the null hypothesis of "Series are cointegrated" cannot be rejected in favor of the alternative hypothesis of "no cointegration". Therefore, the findings of the test demonstrated that there is a cointegration relationship among REC, OP, GDP, and CO2 emissions.

Hence, following the confirmation of the cointegration among the variables, the long-term relationship is examined. The CCR method is employed to analyze the long-run relationship among the variables. The results of the estimations are presented in Table 4.

The estimation findings showed that oil price positively and significantly impacts REC. A 0.16% increase in REC is associated with a 1% increase in the oil price. This result can be interpreted that when compared to conventional fossil fuels, renewable energy sources may be more cost-competitive due to rising oil prices. The cost advantage of renewable energy may grow with rising oil prices, leading to a rise in its adoption. Additionally, the rise in oil prices might stimulate more investment in renewable energy initiatives as governments, corporations, and investors actively explore alternative options to manage energy expenses and decrease reliance on unpredictable fossil fuel markets. Hence, elevated oil prices could incentivize China to increase its investments in domestic renewable energy sources, fostering energy diversification and diminishing dependence on imported fossil fuels. This result aligns with previous studies by Deniz (2019) Positive for oil-importing countries, Azad et al. (2014) for Australia, Apergis and Payne(2014a) for 25 OECD countries, Padhan et al. (2020) for OECD members, Nguyen and Kakinaka (2019) for low- and high-income economies, Chen et al. (2021) for less democratic countries revealed a positive and statistically significant impact of oil prices on REC.

We also found that GDP positively affects REC in China. The positive influence of GDP on the REC supports the idea that economic growth and rising incomes stimulate energy demand, leading to the development of renewable energy resources. Given the substantial expansion of China's economy, there has been a corresponding rise in its energy demand. From 1990 to 2022, China's GDP surged, rising from 360.86 billion to 17.88 trillion (World Bank, 2023). This economic expansion has empowered China to invest in advancing renewable energy technology and infrastructure, increasing the use of renewable energy sources. Between 1990 and 2022, primary energy from renewable sources increased from 4.72% to 15.95% (Ritchie and Roser, 2022). Furthermore, our findings are in alignment with research outcomes from numerous investigations, including those by Sadorsky (2009), Apergis and Payne (2014b), Omri and Nguyen (2014), Nguyen and Kakinaka (2019), Mukhtarov et al. (2020), Karacan et al. (2021), Mukhtarov et al. (2021), Rahman and Sultana (2022), Mukhtarov et al. (2022b), Wang et al. (2022), and Mukhtarov and Mikayilov (2023).

We observe that CO2 emissions positively influence the adoption of renewable energy over the long term. This finding suggests that higher CO2 emissions could raise public awareness about the harmful influence of fossil fuels on the environment and climate. This increased awareness may lead to greater policy support and a higher demand for renewable energy sources. There could be a growing inclination among governments, businesses, and individuals to invest in and adopt renewable energy technologies to mitigate environmental impact. Several studies, including those by Apergis and Payne (2014b), Omri and Nguyen (2014), Omri et al. (2015), Uzar (2020), and Mukhtarov et al. (2023), among others, have also highlighted the positive impact of CO2 emissions.

7. Conclusion and policy implications

This study explores the influence of oil prices, GDP, and CO2 emissions on REC in China. After testing the stationarity of variables through the unit root test, the possibility of a shared long-term movement among

Table 1
An overview of previous empirical research.

Study	Time Spanning	Country/Country Group	Type of Analysis	Findings (Effect of OP on REC)
Sadorsky (2009)	1980–2005	G7countries	Panel	Negative (sig.)
Marques and Fuinhas (2011)	1990–2006	24European Union countries	Panel	Insignificant
Salim and Rafiq (2012)	1980–2006	6emerging economies	Panel	Insignificant effect (Brazil, India, Philippines, and Turkey) Negative (sig.) (China and Indonesia)
Payne (2012)	1949–2009	USA	Time series	No causality between RE and real OP
Apergis and Payne (2014a)	1980–2011	25 OECD countries	Panel	Positive (sig.)
Apergis and Payne (2014b)	1980–2010	7 Central American countries	Time series	Positive (sig.)
Tuzcu and Tuzcu (2014)	1985–2007	7 OPEC members	Panel	Insignificant effect
Azad et al. (2014)	1990–2011	Australia	Gen. Methods of Moments	Positive (sig.)
Omri and Nguyen (2014)	1990–2011	64 countries	Panel	Negative
Omri et al.(2015)	1990–2011	64 countries	Panel	Positive (sig.)
Apergis and Payne (2015)	1980–2010	11 South American	Panel	Positive (sig.)
Brini et al.(2017)	1980–2011	Tunisia	Time series	A unidirectional causality from OP to RE Absence of cointegration link
Alege et al. (2018)	2001–2014	40countries in Sub-Saharan African countries	Panel	No cointegration link No causality
Troster et al. (2018)	1989–2016	USA	Time series	Absence of causality between OP and RE
Nguyen and Kakinaka (2019)	1990–2013	107countries	Panel	Positive(low- and high-income economies), Insignificant and negative(middle-income economies)
Deniz (2019)	1995–2014	Oil importing and exporting countries	Panel	Positive (sig.) (oil-importing countries) Negative (sig.) (oil-exporting countries)
Mukhtarov et al. (2020)	1992–2015	Azerbaijan	Time series	Negative (sig.)
Padhan et al. (2020)		OECD	Panel	Positive (sig.)
Murshed and Tanha (2021)	1990–2018	Bangladesh, India, Pakistan, andSri Lanka	Panel	Negative (sig.)
Bamati and Roofi (2020)	1990–2015	25countries	Panel	Positive (sig.)
Karacan et al. (2021)	1990–2015	Russia	Time series	Negative (sig.)
Mukhtarov et al. (2021)	1992–2015	Kazakhstan	Time series	Negative (sig.)
Dogan et al. (2021)			Panel	Positive (sig.)
Chen et al. (2021)	1995–2015	97 economies	Panel	Positive (sig.) for less democratic countries Insignificant for more democratic countries.
Sahu et al. (2022)	1970–2014	US	Time series	Positive (sig.)
Mukhtarov et al. (2022b)	1980–2019	Iran	Time series	Negative (sig.)
Samour and Pata (2022)	1985–2016	Turkey	Time series	Negative (sig.)
Rong and Qamruzzaman (2022)	1990–2021	United States, China, India, Japan, South Korea	Time series	Positive (sig.) (long run)
Zaghdoudi et al. (2023)	1992Q1-2021Q3	China	Time series	Positive

Source: Updated from Mukhtarov et al. (2022b).

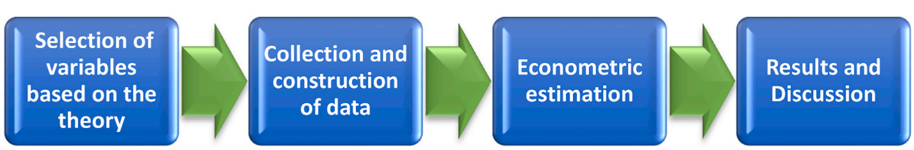

Fig. 4. The methodology flowchart for the empirical analysis.

these variables was examined. The Park added variables cointegration test was employed to assess the cointegration relationship among the variables. The results verify a cointegrating relationship among OP, REC, GDP, and CO2 emissions. Using the CCR technique, the long-term impact of oil prices, GDP, and CO2 emissions on REC was evaluated. The CCR results indicated a positive and statistically significant influence of oil price, GDP, and CO2 emissions on the REC.

The study findings have important policy implications, which are summarized as follows. First, China should implement enhanced incentive programs, such as subsidies, tax credits, and grants, to attract both local and foreign investors to renewable energy projects. These incentives can help offset initial costs and encourage greater adoption. Second, the energy infrastructure should be continuously modernized to accommodate a larger capacity of renewable energy sources. Third, there is a need to raise public awareness regarding the environmental repercussions of fossil fuel use and the advantages of renewable energy through the implementation of campaigns. Encourage eco-friendly habits and energy-efficient living. Fourth, the government should lower entrance barriers and streamline regulatory procedures for renewable energy projects. Fifth, laws and regulations should encourage distributed energy production and storage. Sixth, China should cooperate with global organizations and other nations to exchange expertise, advanced technology, and optimal methodologies in the field of

Table 2
Unit root test outcomes.

Variables	The ADF test	
	Level	First difference
REC	−1.098	−2.001**
OP	−1.341	−5.037***
GDP	−1.534	−2.093**
CO2	−1.486	−3.102***

Notes: **and *** denote rejection of the null hypotheses at the 5% and 1% significance levels.

Table 3
The findings of the Park added variables cointegration test.

	Value	df	p-values
Chi-Square	0.9206	2	0.63

Notes: "Series are cointegrated" is the test's null hypothesis.

Table 4
Outputs of CCR.

Variables	Coefficients	t-Statistics	p-values
OP	0.16	2.016	0.05
GDP	0.39	2.697	0.01
CO2	1.70	6.386	0.00
C	5.33	2.013	0.05

Note: Dependent variable = REC, C is constant. The estimations included the dummy variables I1996 (which equals one in 1996 and zero at other times) and SI2014 (which equals one until 2014 and zero after that) as deterministic regressors.

renewable energy. Therefore, enforcing a blend of these measures might aid in achieving a more sustainable and varied energy composition in China, lessening reliance on oil and alleviating environmental consequences.

We acknowledge the limitations of this study, which can guide the design of future studies. Firstly, the data utilized only extends until 2020, meaning the effects of the post-COVID-19 era, the geopolitical risks from the Russia-Ukraine conflict, and recent tensions in the Middle East are not included in the analysis. Future research would benefit from incorporating these factors. This study also does not incorporate social and institutional variables in the estimation. Including these factors would offer more comprehensive insights for formulating environmental policy recommendations.

CRediT authorship contribution statement

Shahriyar Mukhtarov: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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