RESEARCH ARTICLE

Clarifying the relationship among green investment, clean energy consumption, carbon emissions, and economic growth: a provincial panel analysis of China

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Abstract

As a financial activity with the main purpose of ecological protection and environmental governance, green investment has important practical significance for promoting sustainable economic development. Previous studies have not addressed the relationship between green investment, clean energy consumption, carbon emissions, and economic growth. We use panel data from 30 provinces and cities in China from 2003 to 2017 to build a simultaneous equation model, which can evaluate the nonlinear relationship and avoid the endogeneity of the model. The research results show that, firstly, green investment has a significant positive impact on clean energy consumption and economic growth. However, it has no significant effect on carbon dioxide emissions. Second, the curve of clean energy consumption and per capita GDP conforms to the positive U-shaped characteristic, while the curve of carbon emissions and per capita GDP conforms to the EKC curve, meeting the inverted U-shaped characteristic. And the inflection point of clean energy use occurred earlier than the inflection point of CO_2 emissions. When per capita GDP is greater than 105,735.93 (RMB), the use of clean energy will increase, and carbon dioxide emissions will decrease, thereby achieving a win-win situation for the environment and the economy. Finally, according to the survey results, it is suggested that green investment is an effective means to encourage clean energy consumption and economic growth.

Keywords Green investment · Clean energy · Economic development · Simultaneous equation model · Carbon emissions

Introduction

Since China's reform and "opening up" period, the country's economy has developed rapidly, and problems such as shortages of energy resources and increasing environmental

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Highlights

• The role of green investment on carbon dioxide emissions and clean energy consumption was evaluated.
• Nonlinear relationships between economic growth and clean energy consumption were analyzed.
• The specific forms and turning points of economic growth on clean energy and CO_2 emissions.

Responsible editor: Roula Inglesi-Lotz

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pollution have followed (Zhou et al. 2020). Energy is the foundation and driving force of a country's economic and social development. Thus, changes in energy consumption structure directly affect a country's economic structure, which in turn affects the green, healthy, stable, and long-term development of the economy and society. Currently, China's energy supply is still dominated by natural fossil fuels such as coal, oil, and natural gas, and energy development and utilization have almost always occurred with a low efficiency and high consumption (Ivanovski et al. 2021; Cai et al. 2018). The development of clean energy is generally regarded as one of the most important steps in mitigating pollutant emissions and climate change (Dong et al. 2018; York and Bell 2019). In anticipation of the "14th Five-Year Plan," according to the "China-EU Joint Statement on Climate Change" (2019), China plans to increase the proportion of non-fossil fuels to produce primary energy by 2030. To ensure an increase to 20%, China will increase its nationally determined contribution, adopt more powerful policies and measures to ensure that the nation's carbon dioxide emissions reach their peak by 2030, and strive to achieve carbon neutrality by 2060. This

is similar to other countries' commitments to minimize global warming impacts. In 2016, the People's Bank of China and seven ministries and commissions issued the "Guiding Opinions on Building a Green Financial System," which defined green finance as considering environmental protection as a policy prerequisite, taking potential environmental risks and returns as the content for evaluation, and providing investment, financing, and financing for environmentally friendly projects, operation, and other financial services (Ren et al. 2020; Wang and Zhi 2016). The purpose of developing green finance is to embed financial development in the positioning and vision of sustainable development and use financial tools to guide funds to the green sector. As an important part of green finance, green investment considers energy conservation and environmental protection as its main goals (Li and Gan 2021). This approach analyzes green development from the perspective of financial support and proposes action items; this is conducive to guiding the flow of financial funds and promoting green investment entities to actively invest in green industries, which are of considerable importance in improving the level of economic development, saving resources, and protecting the environment.

According to the "2018 China Energy Statistics Yearbook," China's energy consumption structure is roughly divided into coal, oil, and natural gas consumption and hydro, nuclear, and wind power (also known as "primary power and other energy") consumption. The changes in China's primary energy, CO_2 emissions, PGDP, and environmental protection investments are discussed in the following paragraph. In recent years, the proportion of coal consumption declined from 68.5 (2000) to 60.6% (2017); oil consumption decreased from 22.2 (2000) to 18.9% (2017). This decline in oil consumption was consistent with the change in the proportion of coal consumption, but the degree of change in the former was not large. In contrast, the proportion of clean energy consumption has shown an upward annual trend, with obvious changes. Although the proportion of coal consumption in the energy consumption structure has declined, China's total coal consumption has always accounted for approximately 2/3 of its total energy consumption, and CO_2 emissions have risen slowly after 2013. This decline indicates that China's environmental governance has significantly increased, and the environmental situation has improved. Green investment also continued to increase from 2000 to 2017. However, overall, resource and environmental constraints accumulated throughout long-term rapid development have become increasingly prominent, and ecological and environmental protections are still inadequate. China's per capita GDP increased from 7912.08 (RMB) (2000) to 59,855.25 (RMB) (2017) (CSY, 2018), but environmental protections have not yet accounted for economic and social development, and the nation's environmental carrying capacity has reached or approached its upper limit. Heavy environmental pollution, considerable

ecological damage, and high environmental risks have become prominent shortcomings in comprehensively building a well-off society (Dong et al. 2018).

Compared with traditional investment, the biggest difference between green investment and traditional investment lies in how the two investment models deal with the relationship between economic growth and environmental protection. This is mainly related to the background in which they are produced. The traditional investment model originated from the extensive production model in the past, focusing only on economic benefits, and blindly soliciting and discharging pollutants, and not considering environmental protection and sustainable development. In the context of the increasingly intensified contradiction between economic growth and environmental pollution, how to realize the economic and environmental benefits of investment at the same time has become a problem that all investment entities need to consider. Green investment has emerged as the times require. Can green investment be used to coordinate economic growth and environmental protection? The contradiction is the key to my country's promotion of the construction of an ecological civilization and its development transformation (Chen and Ma 2021). The threat of global warming and climate change has focused people's attention on the relationship between economic growth and environmental pollutants. As an important starting point for my country's implementation of green finance, green investment can effectively improve environmental quality, reduce pollution, and promote the sustainable development of the economy and society. The introduction of financial services into the energy conservation and environmental protection industry through green investment can promote the transformation of the energy consumption structure, from traditional fossil energy to clean energy (Adamantiades and Kessides 2009; Musibau et al. 2021). Clean energy is a kind of green energy that does not emit pollutants. Vigorously developing clean energy will not only ensure energy security and control pollution, but it will also promote the upgrading of industrial structures and achieve green economic growth (Liu et al. 2020b). According to the International Renewable Energy Agency (IRENA), the transformation of the world's energy sector from non-renewable energy to renewable energy is moving towards decarbonization. This may help in achieving 90% of the required CO_2 emission reduction targets. Renewable energy is an important part of energy supply, which can improve the existing energy structure, balance market contradictions, and protect the environment (Khan et al. 2021). So far, empirical research has focused on investigating the causal relationship between energy consumption and economic growth, as well as the causal relationship between energy consumption and pollutant emissions (Chontanawat et al. 2008; Ozturk 2010; Alkhathlan and Javid 2013; Omri 2013; Pardo Martínez 2013; Al-mulali 2014), and the use of modern developments in time series econometrics related to causality

testing for testing the causal relationship between nuclear energy consumption, renewable energy consumption, and carbon dioxide emissions.

Our research focuses on the existing theoretical and empirical literature and regards green investment as a key emerging determinant of clean energy consumption and economic growth absent in the previous literature. The biggest innovation of this research is to use panel data from 30 provinces and cities in China from 2003 to 2017 to construct a simultaneous equation model to examine the relationship between green investment, clean energy consumption, carbon dioxide emissions, and economic growth. More importantly, simultaneous equations can solve the endogenous problems caused by simultaneous deviations. The main reason for studying the relationship between green investment, clean energy, carbon dioxide emissions, and economic growth is that green investment plays an important role in the debate on environmental protection and sustainable development, and our findings are even more valuable for formulating energy and environmental policies related to green investment and financing.

This research attempts to explore whether green investment can achieve the goal of simultaneously promoting economic development and environmental improvement. The main contributions are as follows: First, most of the existing literature only considers the relationship between economic growth, green energy consumption, and carbon dioxide emissions. This article takes a different perspective and considers green investment, clean energy consumption, carbon dioxide, and economic growth in a unified manner. In the analysis framework of the empirical analysis of green finance, represented by green investment, on my country's economic development level, clean energy consumption, and CO_2, we have enriched the theory of financial support. Second, the panel simultaneous equation model is used to overcome the endogenous problem of causality between variables and avoid estimation bias. Third, most existing studies have investigated the linear relationship between variables. This study re-examined the nonlinear relationship between green investment, clean energy consumption, carbon dioxide emissions, and economic growth. Economic phenomena are complex and changeable, leading to many nonlinear relationships between economic variables, and the relationship between the curves is further investigated based on the obtained nonlinear model. Finally, to improve the robustness of the results of this research, the research results are grouped according to the eastern, central, and western regions of China. The research results can be used to ensure the future development of clean energy consumption and green investment in a healthier and more sustainable way and to provide references for the formulation of relevant policies and measures.

The rest of the research is as follows: The "Literature review and hypotheses" section provides a literature review of the relationship between green investment, clean energy

consumption, carbon emissions, and economic growth. The "Methodology" section introduces the source of the data and the specifications of the empirical model and reports preliminary statistics. The "Empirical results and analysis" section introduces the empirical results and provides an explanation. Finally, the "Conclusions and policy implications" section introduces conclusions and policy implications.

Literature review and hypotheses

Green investments

Most foreign scholars refer to green investment as "socially responsible investment," believing that green investment is a behavior that considers environmental standards, social responsibility, and benefits (Eyraud et al. 2013; Karásek and Pavlica 2016). In combination with incentives and energy transitions, if greater investment will help reduce the proportion of total energy consumption involving coal use, the investment is regarded as green (Xu et al. 2017). Domestic scholars more often regard green investment as "environmental protection investment" that is closely related to the environmental pollution and associated economic losses caused by China's rapid economic growth in the twenty-first century. These scholars have suggested new factors that simultaneously consider economic growth and reduce environmental pollution; these investments should cause a shift to a green and low-carbon economy (Carraro et al. 2012). Green investment may also be aimed at reducing greenhouse gas emissions and promoting policies and programs to protect the environment and climate.

The relationship between green investment and the economy

Hypothesis 1: Green investment promotes the use of clean energy.

At present, studies have reported that financial support can either promote or inhibit the use of clean energy. Lee (2013) found a positive correlation between foreign direct investment and G20 clean energy use during dual regression. Ren et al. (2020) used a vector error correction model to analyze the relationship between the level of green finance development and non-fossil energy consumption. China's green finance industry is developing rapidly, and the improvement of the country's green finance development index has promoted an increase in the use of non-fossil energy. Raghutla et al. (2021) noted that foreign direct investment is beneficial in encouraging clean energy consumption by converting more funds into clean energy projects and has played a considerable role in promoting clean energy consumption. Tolliver et al. (2020)

stated that the green bond market has expanded dramatically, and proceeds are increasingly being allocated to renewable energy. These actions stimulate the allocation of green bond capital to promote emissions reductions, thereby helping to fill the gap in low-emission and renewable energy financing. However, Charfeddine and Kahia (2019) found that financial support had a negative impact on the use of renewable energy, indicating that the financial development of countries in the Middle East and North Africa may have reduced the use of renewable energy. Zahan and Shuai (2021) used the autoregressive distributed lag model (ARDL) method to investigate the impact of China's green investment on clean energy consumption and carbon dioxide emissions from 1998 to 2019. The results show that in the long run, green investment tends to have a positive impact on China's clean energy consumption. Guo et al. (2021) examined the impact of green innovation and investment in the energy sector on the provincial and regional environment in China from 1995 to 2017, and the results show that green innovation and investment in energy can improve environmental quality.

> **Hypothesis 2:** Green investment promotes economic growth.

Some researchers have concluded that financial support can either promote or inhibit economic growth (King and Levine 1993; Roubini and Sala-i-Martin 1992). Apergis and Payne (2010), Shahbaz et al. (2017), and Tang and Tan (2013) noted that economic growth could be promoted through the introduction of energy investments. Shahbaz et al. (2013) studied Malaysia's financial development and economic growth from 1971 to 2011 and found a two-way causal relationship between them. Additionally, Zhou et al. (2020) constructed a model of the impact of green finance on economic development and indicated that the development of the former may promote the latter. He et al. (2019) took 150 listed renewable energy companies in China as an example and used panel threshold regression study to show that when the green credit exceeds a certain amount, the green credit resources flowing into the renewable energy industry are conducive to promoting the development of green economy.

Relationship between green investment and CO_2 emissions

> **Hypothesis 3:** Green investment has a significant effect on reducing CO_2 emissions.

At present, some studies have concluded that financial support can range from increasing to suppressing CO_2 emissions, or they may have no effect whatsoever. Shen et al. (2021) used a new cross-section-enhanced autoregressive distribution lag (ARDL) method to find the long- and short-term effects of

research variables on carbon emissions; this ARDL estimate confirmed the positive impact of energy consumption and financial development on CO_2. Green investment is negatively correlated with CO_2, whereas national natural resource rents are positively correlated with carbon emissions. Ren et al. (2020) used data from 2000 to 2018 and used a vector error correction model to analyze the relationship between the level of green finance development, non-fossil energy consumption, and carbon intensity. China's green finance industry is developing rapidly. The improvement of the green finance development index and the increase in the use of non-fossil energy will help reduce carbon intensity. Raghutla et al. (2021) noted that foreign direct investment inflows had a significantly negative impact on CO_2 emissions. Gu et al. (2021) studied the quasi-natural experiment of the extreme event of PM 2.5 surge in China in 2011. This event significantly increased public concerns about smog. Companies with serious pollution have increased green investment to ease the pressure. Chen and Ma (2021) used the data of listed Chinese energy companies from 2008 to 2017 to explore the impact of green investment on corporate performance, and the results show that green investment can promote environmental performance. Musibau et al. (2021) investigated the relationship between energy efficiency, green energy investment, and energy innovation in 9 highly industrialized countries. Based on the environmental Kuznets hypothesis (EKC), the quantile-upper quantile regression method is used for the data obtained from 1980 to 2018. Research shows that increasing investment in renewable energy and energy efficiency can reduce carbon emissions and improve environmental quality.

However, green investment had no significant effect on CO_2 emissions. Hammoudeh et al. (2020) examined green bonds and other assets (including US conventional bonds). They observed a time-varying causal relationship between the Seoul clean energy (stock) index and the price of CO_2 emission allowances. Moreover, their recursive evolution causality algorithm showed that the causality relationship between the clean energy index and green bonds with CO_2 emissions was not significant. Charfeddine and Kahia (2019) revealed that financial development had no significant impact on effectively mitigating CO_2 emissions in the Middle East and North Africa. Zahan and Shuai (2021) used the ARDL model to study the negative impact of green investment on China's carbon dioxide emissions, but in the long run, it has little impact on carbon emissions.

Relationship between economic growth and clean energy consumption

> **Hypothesis 4:** Economic growth has a nonlinear impact on clean energy consumption.

Many studies have examined the linear relationship between energy consumption and economic growth. Yoo and Jung (2005), Wolde-Rufael (2010), and Heo et al. (2011) studied South Korea, India, and Iran, respectively, and concluded that there was a one-way causal relationship between nuclear energy consumption and economic growth and clean energy consumption contributed to economic growth. Apergis and Payne (2010), Lin and Moubarak (2014), Sebri and Ben-Salha (2014), and Kahia et al. (2016) studied Eurasia, China, the BRICS, and the Middle East and North Africa, respectively, and concluded that economic growth related to nuclear energy consumption has a two-way causal relationship. Zhang et al. (2020a, 2020b) calculated the two-dimensional decoupling state of the energy footprint of 39 countries from 1995 to 2014. According to the results of the study, 12 of these developed countries have ideal two-dimensional decoupling, where the energy footprint declines, while the economy is at a high income level and continues to grow.

Others have recognized the possibility of a nonlinear relationship between energy consumption and economic growth. Wang and Wang (2020) used a panel quantile regression to show that the impact of renewable energy consumption on economic growth is positive, i.e., an increase in renewable energy consumption contributes to economic growth. In addition, this positive relationship changes with the threshold value, which means that increasing renewable energy consumption has a nonlinear effect on promoting economic development. Zhou and Li (2019) stated that the role of renewable energy consumption in economic growth and emissions is heterogeneous, and the relationship between renewable energy consumption and economic growth is W-shaped. The relationship between renewable energy consumption and emissions is an inverted N-shape, and the relationship between non-renewable energy consumption and emissions is a √-shaped curve. Awodumi and Adewuyi (2020) and Shahbaz et al. (2017) also used the nonlinear ARDL method to study the nonlinear effects of economic growth and carbon emissions.

Relationship between economic growth and CO_2 emissions

Hypothesis 5: Economic growth has a nonlinear impact on CO_2 emissions.

Many scholars have also noted that the relationship between economic growth and environmental pollution conforms to the inverted U-shaped curve of the EKC. Grossman and Krueger (1994) used the inverted U-shaped curve relationship between per capita income and distribution to study the link between economic growth and environmental quality. In the early stages of economic development or growth, environmental quality first deteriorates. Furthermore, He and Richard (2010), Esteve and Tamarit (2012), Baek and Kim

(2013), Kanjilal and Ghosh (2013), Nasir and Rehman (2011), Saboori et al. (2012), and Sephton and Mann (2013) studied the economic growth of Canada, Spain, South Korea, India, Pakistan, and Malaysia, respectively, and their inverted U-shaped relationship between CO_2, which is in accordance with the environment. Alam et al. (2016) verified that there was an inverted U-shaped relationship between per capita CO2 emissions and per capita real GDP in Indonesia, China and Brazil with statistical significance, conforming to the Environmental Kuznets curve. However, India shows a positive U-shaped relationship (Narayan and Narayan 2010). Kang et al. (2016) tested the EKC hypothesis of China's CO_2 using a spatial panel data model. Ding et al. (2019) studied the significant inverted U-shaped relationship between economic growth and inhalable particulate pollution in the Beijing-Tianjin-Hebei region. Soytas et al. (2007) studied the relationship between GDP and CO_2 in the USA from 1960 to 2004 and found that it did not conform to the EKC curve. Kang et al. (2016) tested the EKC hypothesis of China's CO_2 using a spatial panel data model. Ding et al. (2019) studied the significant inverted U-shaped relationship between economic growth and inhalable particulate pollution in the Beijing-Tianjin-Hebei region. Song et al. (2019) used the two-dimensional decoupling theory to study the decoupling relationship between economic development and carbon dioxide emissions from 1965 to 2016. For China and the USA, the EKC curve of carbon emissions and per capita GDP satisfies the inverted U-shaped characteristic. The per capita GDP thresholds of China and the USA are 7999.5 US dollars and 50,980.52 US dollars, respectively.

In summary, existing research provides a certain reference value and significance for follow-up-related research, but no consensus on the research conclusions has been reached yet. The reason for this range in explanations may be that many existing studies have used widely variant panel estimation methods to examine the relationship between renewable energy consumption and economic growth, such as panel cointegration, panel dynamic least squares, fully corrected least squares, and panel vector error correction. However, to the best of our knowledge, most of the existing literature only considers the relationship between economic growth, energy consumption, and CO_2 emissions. Only a small part of the literature has noted the potential nonlinear relationship between renewable energy consumption and economic growth. The clean energy industry has received increasing attention in the past 10 years. At present, there is no research on the interaction between special green investment, clean energy consumption, carbon emissions, and economic growth at home and abroad. Green investment, economic growth, clean energy consumption, and CO_2 emissions are currently the primary foci of research in the field of environmental economics at home and abroad. The research framework of the hypothesis is shown in Figure 1.

Methodology

Variable settings and data sources

This study incorporates the annual panel data of 30 provinces in China from 2003 to 2017 (due to a lack of key data, Tibet, Taiwan Province, Hong Kong Special Administrative Region, and the Macao Special Administrative Region are excluded). The missing values were filled via interpolation. The data of green investment comes from China Environmental Statistics Yearbook, the data of clean energy consumption comes from China Energy Statistics Yearbook, the data of CO_2 emission comes from CEADS. http://www.ceads.net/, and the data of per capita GDP comes from China Statistical Yearbook. In the control variables, except the proportion of coal consumption structure that comes from China Energy Statistical Yearbook, other data comes from China Statistical Yearbook.

(1) Green investment (GI) reflects the proportion of GDP that is recovered through investing in environmental pollution control efforts (Liao and Shi 2018). At present, domestic statistics on green investment can be divided into large, medium, and small diameters. Among them, the small caliber mainly includes investment in environmental pollution control, such as industrial environmental pollution, urban environmental pollution, agricultural environmental pollution, and other aspects of investment. The medium caliber increases investment in environmental protection technology development and comprehensive energy development and utilization. Large-caliber green investment is defined from a macro point of view, which includes broader contexts; that is, all the investment that can improve "green GDP" belongs in this category. Due to the availability of data, this paper adopts a small diameter; that is, the green investment referred to in this paper is the investment in environmental pollution control of each province divided by the proportion of GDP (Zahan and Shuai 2021).

(2) Clean energy consumption (CE energy: Clean energy refers to energy that does not emit pollutants and can be directly used for production and life). This includes nuclear energy and "renewable energy." Hydroelectric power generation relies on incoming water, and thermal power generation relies on coal burning. Thermal power

plants have no competitive advantage in the face of low-cost hydropower. The feed-in tariff for hydropower is reported to be a few cents initially, but thermal power plants have not yet reached this level. Thermal power (mainly coal) has made a huge contribution to China's economic development, and the country's entire power system was originally designed and operated around thermal power owing to historical reasons and development stages. As a large power consumer, China's residential and industrial electricity consumption is among the highest in the world. The combustion of coal produces large amounts of pollutants such as sulfur dioxide and CO_2. Therefore, power generation will affect the use and combustion of coal, thereby affecting the quality of the ecological environment. Because clean energy is mainly used for power generation in China, in this study, the level of development, utilization, and consumption of clean energy and its contribution to GDP are all measured by the amount of clean energy generation (Liu and Dong 2021). Clean energy consumption refers to all major clean energy sources used for power generation in each region, including hydropower, solar energy, wind energy, geothermal energy, ocean energy, biomass, and other clean energy sources (Cai et al. 2018). Each statistical yearbook only counts the provincial total energy consumption or power generation for primary energy (hydropower) and clean energy sources. Therefore, clean energy generation is used instead of clean energy consumption.

(3) CO_2 emissions: China's CO_2 emissions data were extracted from the official website of China's emissions accounts and datasets (Ren et al. 2020).

(4) Economic growth: Expressed in real GDP per capita (Wang and Wang 2020). This represents the population average of the total value of goods and services produced at market prices in a country in a certain period (usually a year). In economics, real GDP is generally used to measure the degree of economic development in a country.

Combining existing research and our previous discussion, we also controlled a set of urban characteristic variables in the simultaneous equation regression model to minimize the errors caused by variable omissions. The control variables are as follows:

Fig. 1 Research framework. Note: ▭ , ▭ represents a one-way linear relationship, ⬒ , ⬒ represents the nonlinear relationship between variables.
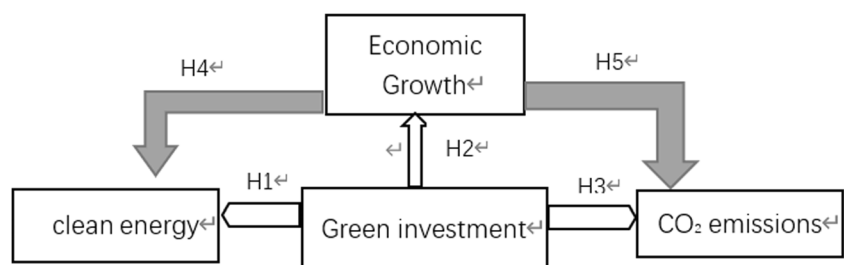
(1) Technological innovation (TECH): This variable is expressed by the number of technological patent applications granted by provinces and cities (Ahmed et al. 2016; Bai et al. 2019; Liu and Zhang 2021).

(2) Degree of openness to FDI: This study uses foreign direct investment to measure this variable because it attracts foreign investment in the process of opening to the outside world. When the severity of environmental regulations in the inflowing country is low, pollution-intensive companies can do business, increase environmental pollution and carbon emissions, and cause "pollution." Some scholars, such as Liao and Shi (2018) and Raghutla et al. (2021), have also used this indicator as a control variable or explanatory variable.

(3) Strength of environmental regulations (ER): Many studies have evaluated this variable's impact on pollution reduction (Zhang et al. 2020a, 2020b; Liu et al. 2020b). According to previous studies, this important indicator is measured by the proportion of sewage charges in the output value of the secondary industry. In theory, the stronger the environmental supervision, the higher the proportion of sewage charges.

(4) Urbanization level (URB): This variable represents the population structure, using the ratio of the urban population to the total population. Liu et al. (2020a, 2020b) used this variable to control the level of economic development; in the later stages of urbanization, a high population concentration will lead to a decline in per capita energy consumption. Concurrently, owing to China's high population density, the increase in urbanization rate will result in a significant drop in per capita energy consumption. Therefore, the urbanization rate and environmental degradation have an inverse relationship.

(5) Industrial structures (STR): China's economic growth has gradually changed from industry-centric to service-centric. The contribution of industry to economic growth has decreased annually, whereas that of the service industry has increased. The development of the service industry mostly does not require sacrificing environmental resources, whereas the development of industry is often accompanied by high emissions, pollution, and energy consumption. Changes in the nation's industrial structure will have an important impact on the ecological environment. This study uses the proportion of the tertiary industry to measure China's industrial structure (Liu et al. 2020a, 2020b; Zhou et al. 2020).

(6) Per capita education expenditure (PEDU): The expected signs were positive. The ratio of education expenditure to employees is an important indicator of human capital. According to the endogenous growth theory, knowledge accumulation can promote economic growth (Zhou et al.,2020).

(7) Transportation convenience (TRAN): This represents the per capita highway mileage (km/person). With an increase in traffic convenience, people will commute to work, and there will be more traffic and trade exchanges. Highly developed transportation can foster travel within and between regions. This provides convenience and concurrently leads to the consumption of energy such as gasoline, which in turn affects CO_2 emissions.

(8) Proportion of coal consumption structure (COAL): At present, China's coal consumption accounts for most of its overall energy consumption, and the development of various industries has been inseparable from coal, such as thermal power generation, steelmaking, and winter heating in the north (Liu et al. 2020a, 2020b; Ding et al. 2019).

Specification of econometric models

Equation (1) studies the impact of green investment, economic growth, CO_2, and some control variables on clean energy consumption. To illustrate the nonlinear impact of economic growth on the transformation of energy structure, the regression model in Equation (4) includes the first and second terms of GDP per capita. In addition, the control variable U includes the intensity of ER, technological progress (TECH), industrial structure (STR), coal consumption ratio (COAL), and per capita education expenditure (PEDU).

Equation (2) explores the linear impact of green investment, economic growth, and clean energy on CO_2 emissions. Equation (5) is based on the EKC theoretical hypothesis (Grossman and Krueger 1994). When creating the environmental Kuznets curve, economic growth is proposed through the scale, technical, and structural effects on environmental quality. To verify the establishment of the EKC, the primary and secondary terms of GDP per capita were introduced (Dinda et al. 2004; Shahbaz et al. 2012). The control variable V includes the ER, STR, PEDU, and TRAN.

The explained variable of Equation (3) is economic growth, expressed in per capita real GDP, and is used to identify the linear impact of green investment, clean energy consumption, and CO_2 on economic growth. Equation (6) considers the primary and secondary terms of clean energy consumption to analyze the possible nonlinear effects between them (Huan et al., 2020), the development of a region, and the amount of pollution. However, economic development does not necessarily negatively impact the ecological environment, although this dynamic is dependent on the local economic structure. The control variable W includes the ER intensity, PEDU, and TECH.

Based on this information, the three different functions of clean energy consumption and CO_2 emissions are as follows: green investment will affect clean energy development, CO_2

emissions, and economic growth. Moreover, clean energy development and CO_2 emissions will affect economic growth. Under these circumstances, it is difficult to avoid endogeneity in building a single regression model. This problem can be solved by constructing a simultaneous equation model and studying the relationship between the four (Chandrashekar Raghutla et al. 2021; Liu et al. 2020a, 2020b). Therefore, we have established a simultaneous equation composed of regression models in which green investment, clean energy development, CO_2 emissions, and economic growth are explained variables, where GE represents clean energy consumption, greeninv represents green investment, and CO_2 represents CO_2 emissions; pgdp represents economic growth; variable subscripts i and t represent economy and year, respectively; U, V, and W are control vector groups, and individual fixed effects, time fixed effects, and error terms are added to each equation. To avoid heteroscedasticity, take the logarithm of all the variables.

The linear model:

$$CE_{it} = \partial_0 + \partial_1 GI_{it} + \partial_2 PGDP_{it} + \partial_3 CO2_{it} + \delta U + \theta_i \\ + v_i + \varepsilon_{it} \quad (1)$$

$$CO2_{it} = \beta_0 + \beta_1 GI_{it} + \beta_2 PGDP_{it} + \beta_3 CE_{it} + \delta V + \theta_i \\ + v_i + \varepsilon_{it} \quad (2)$$

$$PGDP_{it} = \gamma_0 + \gamma_1 GI_{it} + \gamma_2 CE_{it} + + \gamma_3 CO2_{it} + \delta W \\ + \theta_i + v_i + \varepsilon_{it} \quad (3)$$

The quadratic model:

$$CE_{it} = \partial_0 + \partial_1 GI_{it} + \partial_2 PGDP_{it} + \partial_3 PGDP^2_{it} + \partial_4 CO2_{it} \\ + \delta U + \theta_i + v_i + \varepsilon_{it} \quad (4)$$

$$CO2_{it} = \beta_0 + \beta_1 GI_{it} + \beta_2 PGDP_{it} + \beta_3 PGDP^2_{it} \\ + \beta_4 CE_{it} + \delta V + \theta_i + v_i + \varepsilon_{it} \quad (5)$$

$$PGDP_{it} = \gamma_0 + \gamma_1 GI_{it} + \gamma_2 CE_{it} + \gamma_3 CE^2_{it} + \gamma_4 CO2_{it} \\ + \delta W + \theta_i + v_i + \varepsilon_{it} \quad (6)$$

Empirical results and analysis

Descriptive statistics

We used panel data from 30 provinces in China from 2003 to 2017 to analyze the relationship between green investment, clean energy consumption, carbon emissions, and economic

growth. In order to eliminate heteroscedasticity and ensure the stability of the data, all variables are converted into logarithms, and the descriptive statistical results of the variables are shown in Table 1.

Analysis of unit root

To avoid spurious regression and ensure the unbiasedness and validity of the results, the panel data stationarity test is first required. For the problem of stationarity test, this paper uses the same root statistic LLC and different root statistic ADF-Fisher to carry out the panel unit root test. If the original hypothesis of unit root is rejected in both tests, the sequence is stable. Otherwise it is not. The results of the two tests are shown in Table 2. It can be seen that the main variables have passed the significance test and meet the application requirements of the simultaneous equation model.

Regression results of simultaneous equation model for model

Table 3 shows the regression results obtained through the 3SLS method to estimate the simultaneous Equation models (1)–(6). Equations (1)–(3) are linear models, while (4)–(6) are nonlinear models. The estimation results prove the interaction between green investment, clean energy consumption, carbon emissions, and economic growth in the sample cities during the study period. Next, we will discuss and analyze the regression results of these six equations in detail.

Table 3 reports the estimated results of the simultaneous equations. Columns (1)–(3) consider the linear relationship between green investment, clean energy consumption, CO_2 emissions, and economic growth. Column (1): In the clean energy equation, green investment, CO_2, and economic growth have no significant impact on clean energy

Table 1 Descriptive statistics table

Variable	Obs	Mean	Std. Dev.	Min	Max
lnGI	450	4.7558	1.0738	1.2809	7.2557
lnPGDP	450	10.2341	0.7214	8.2164	11.7675
lnCE	450	4.7117	1.7674	−2.1203	8.0378
lnCO$_2$	450	5.3502	0.8436	2.0222	7.3473
lnTECH	450	0.4208	1.6482	−4.3901	4.1397
lnSTR	450	−0.8763	0.1828	−1.2235	−0.2157
lnFDI	450	3.1371	1.6765	−1.9005	5.8794
lnURB	450	5.3127	1.4481	0.8467	7.9875
lnCOAL	450	−0.1286	0.4200	−2.6771	0.7613
lnER	450	−5.9054	0.7148	−8.1398	−3.8263
lnPEDU	450	7.1748	0.6967	5.5075	8.6595
lnTRAN	450	−5.9568	0.6427	−7.9096	−4.3037

Table 2 Stationarity test result of variable

Variable	Horizontal sequence value		First-order difference sequence value		Conclusion
	LLC	ADF-Fisher	LLC	ADF-Fisher	I(1)
lnGI	−4.817***	60.9326	−7.066***	222.6707***	I(1)
lnPGDP	−10.34***	26.6376	−3.1969***	113.7067***	I(1)
lnCE	−1.8987**	80.0626**	−9.4919***	305.4464***	I(1)
$lnCO_2$	−8.915***	68.607	−11.6073***	314.1314***	I(1)
lnTECH	−4.42***	68.2754	−3.7613***	109.2064***	I(1)
lnSTR	3.0656	109.10***	−4.305***	204.2921***	I(1)
lnFDI	−8.473***	79.2918**	−1.57*	125.4479***	I(1)
lnURB	−5.249***	109.242***	−14.472***	468.1108***	I(1)
lnCOAL	0.2572	69.1189	−9.5548***	252.8228***	I(1)
lnER	−1.9938**	61.7814	−5.8426***	269.9654***	I(1)
lnPEDU	−8.475***	72.6875	−5.8243***	212.8339***	I(1)
lnTRAN	−22.43***	129.744***	−28.209***	285.3899***	I(1)

Notes: I (n) means that the sequence is stationary after n-th order difference. *, **, and *** represent the rejection of null hypothesis of unit roots at the significance levels of 1%, 5%, and 10%, respectively.

consumption. Column (2): In the CO_2 equation, green investment has no significant impact on CO_2 emissions. Column (3): In the economic growth equation, green investment has no significant impact on economic growth. So Hypotheses 1, 2, and 3 are not true. In addition, through the results of models (1)–(3), many core variables are not significant to the dependent variable, and the control variables are not statistically significant to the dependent variable. Therefore, according to the environmental Kuznets theory hypothesis, the quadratic term of GDP per capita is introduced, and this article focuses on the study of nonlinear models.

Further considering the nonlinear effects between the key variables in this study, columns (4)–(6) represent the corresponding estimation results. The green investment in column

Table 3 Basic estimation results of the simultaneous equation model

	Linear model			Quadratic model		
	lnCE (1)	$lnCO_2$ (2)	lnPGDP (3)	lnCE (4)	$lnCO_2$ (5)	lnPGDP (6)
lnGI	0.1094 (0.169)	0.0078 (0.148)	0.0285 (0.779)	1.9399*** (3.121)	−0.0404 (−1.190)	0.0701*** (3.378)
lnPGDP	−3.4471 (−0.616)	1.0606*** (4.088)		−114.653*** (−3.478)	5.8908*** (8.428)	
lnPGDP²				5.3544*** (3.451)	−0.2546*** (−7.236)	
lnCE		0.3756** (1.991)	0.0021 (0.067)		0.0417** (1.978)	0.2126* (1.924)
lnCE²						−0.0234* (−1.866)
$lnCO_2$	1.2578 (0.182)		0.4028* (1.835)	−9.0606*** (−3.352)		0.0775 (1.379)
lnSTR	0.0146 (0.008)		0.0058	5.5505*** (2.869)	7.8872** (2.003)	
lnER	0.0190 (0.095)	−0.0062 (−0.144)	(0.186)	−0.3994 (−1.530)	0.0594*** (3.043)	−0.079*** (−3.556)
lnCOAL	0.0496 (0.015)	0.2316 (1.614)		5.0209*** (3.058)		
lnPEDU	0.8750 (0.197)		0.2314 (1.610)	18.3982*** (3.578)		0.5398*** (6.409)
lnURB		0.0007 (0.283)			0.0022 (0.362)	
lnTECH	0.0261 (0.102)		0.0128 (0.968)	0.9625** (2.209)		0.0352* (1.681)
lnTRAN					−0.6173*** (−7.658)	
lnFDI		−0.0010 (−0.134)			−0.0418** (−2.185)	
cons	23.3066 (0.531)	−6.3763** (−2.384)	6.7526*** (14.116)	509.8936*** (3.499)	−33.1677*** (−8.542)	5.2212*** (6.394)
chi2	2332.2	4321.79	6217.98	387.48	9914.72	21765.78
R-square	0.8725	0.8986	0.9337	−0.2863	0.9580	0.9770

(4) is positive (significantly at the 1% level), indicating that as green investment increases, the region uses more and more clean energy. Green investment has a positive impact on clean energy consumption, and Hypothesis 1 has been verified. In addition, the primary and secondary GDP per capita are significantly negative and positive, respectively, indicating that there is a significant U-shaped relationship between clean energy consumption and economic growth. Hypothesis 4 is verified, indicating that the urban economy developed to a per capita GDP exceeding 44,600 (RMB) during the study period (lnPGDP = 10.706) when economic growth can promote the transformation of energy structure and increase the use of clean energy. During the study period, when the per capita GDP was below 44,600 yuan (RMB), economic development did not accelerate the use of clean energy. The estimated coefficient of CO_2 emissions is significantly negative, indicating that the increase in CO_2 emissions in a certain area hinders the development of green energy. In column (5), the CO_2 coefficient corresponding to green investment is negative. The degree of development of green investment reduces CO_2 emissions; however, the impact is not significant. Therefore, Hypothesis 3 does not hold. The possible reason for this result is that some companies may put too much emphasis on the concept of green investment. The low-carbon environmental protection industry has good profitability and growth, but the risk is high, and the amount of energy saving and emission reduction is small. Activities that provide financial support for green development and carbon emission reduction require the government and related policies to vigorously promote and guide the supply of green finance. In addition, the primary and secondary terms of per capita GDP are significantly positive and negative, respectively, confirming the existence of EKC (Sun et al. 2021) for carbon dioxide emissions and verifying Hypothesis 5. Specifically, carbon dioxide emissions and economic growth show an obvious inverted U-shaped relationship. When the per capita GDP exceeds 105735.92 (RMB) (lnPGDP=11.5687), economic growth promotes CO_2 emission reduction. In addition, the estimated coefficient of clean energy consumption was significantly positive, which means that, on average, clean energy consumption does not significantly reduce CO_2 emissions. Finally, the estimation results in column (6) show that the core explanatory variable green investment promoted economic growth, which verified Hypothesis 2. For every 1% increase in green investment, economic growth would increase by 0.0701% on average. An inverted U-shaped relationship existed between economic growth and the proportion of clean energy consumption. When the power generation of clean energy does not exceed 9.394 billion kWh (lnCE = 4.5427), the use of clean energy can help achieve economic growth. A possible reason for this result is that the development and use of clean energy requires a large investment in labor and material resources as well as a corresponding hard infrastructure, which will increase the

burden of economic growth under certain conditions. Therefore, the economy will be affected by the transition from traditional fossil fuels to green energy, and growth has a negative impact.

Finally, the estimation results in column (6) show that the core explanatory variable green investment promotes economic growth, which verifies Hypothesis 2. For every 1% increase in green investment, economic growth will increase by 0.0701% on average. Economic growth and the proportion of clean energy consumption are in an inverted U-shaped relationship. When the power generation of clean energy does not exceed 9.394 billion kilowatt-hours (lnCE=4.5427), the use of clean energy will help achieve economic growth. One possible reason for this result is that the development and utilization of clean energy requires a large amount of labor and material input, as well as corresponding hard infrastructure, which will increase the burden of economic growth under certain conditions. Therefore, the economy will be affected by the transition from traditional fossil fuels to green energy, which will have a negative impact on growth. Combining China's industrialization development process and economic structural transformation, the relationship between economic growth and clean energy is U-shaped (Zhu et al. 2020), and the relationship between economic growth and CO_2 is inverted U-shaped (Alam et al. 2016; Dong et al. 2018), as shown in Figure 2.

In combining the development process of China's industrialization and the transformation of economic structure, the relationship between economic growth and clean energy is U-shaped (Zhou et al. 2020), and the relationship between economic growth and CO_2 is an inverted U-shape (Alam et al. 2016; Dong et al. 2018), as shown in Figure 2. When the per capita GDP is less than 44,600 (RMB), stage I may show that China is a pre-industrial economy, mainly in the agriculture and light industries. China's industrial, investment, and technology structures tend to be labor and pollution intensive. These structures are characterized by high resource consumption, environmental pollution, and waste. During the high-emission phase, few clean energy sources are used, and CO_2 emissions increase. When the per capita GDP is between 44,600 (RMB) and 105,735.92 (RMB), entering stage II, heavy and chemical industries are developed. The industrial, investment, and technology structure are mainly capital-intensive enterprises. The proportion of clean energy increases, but CO_2 emissions remain high. During the emission phase, the energy structure constantly transforms and is upgraded. When the per capita GDP is greater than 105,735.92 (RMB), reaching stage III, China reaches the post-industrial stage, transitioning from its traditional agricultural economy to service industry-led enterprises. Substantial changes occur to the country's industrial, investment, technical, and energy structures. CO_2 emissions are reduced, energy consumption and industrial emissions are reduced, the
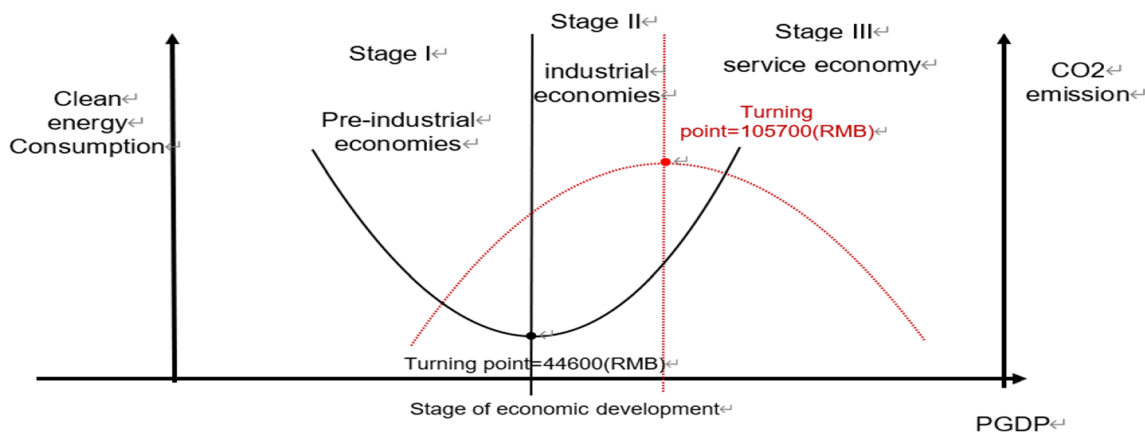
Figure 2. Relationship between economic growth, clean energy, and carbon dioxide. Source: Alam et al. (2016)

industrial base becomes advanced, and clean energy production greatly increases, introducing a win-win scenario.

Robustness test

Based on the above model estimation results, the robustness of the model is further tested to obtain more reliable estimation results, as shown in Table 4. First, considering the time lag of the impact of various economic variables, two methods of robustness testing are adopted. The first one lags the core explanatory variables by one period. The results are shown in (7), (8), and (9), and in the second, all control variables are processed in a lagging period, and the results are shown in (7′), (8′), and (9′). Table 3 reports the corresponding estimation results. The signs and significance of the core variables of the two methods remained basically unchanged, and the results remained robust.

Heterogeneity analysis

Table 5 provides a group analysis of the heterogeneity of the studied variables within the grouped regions of the study area (Chakraborty and Mazzanti 2020; Zhou and Li 2019). The eastern region includes Beijing, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan, and Liaoning; the central region includes Shanxi, Jilin, Hebei, Heilongjiang, Anhui Province, Jiangxi Province, Henan Province, Hubei Province, Hunan Province, Guangxi, and Inner Mongolia; western regions Sichuan Province, Chongqing City, Qinghai Province, Guizhou Province, Yunnan Province, Shaanxi Province, Gansu Province, and Ningxia and Xinjiang are missing data. The eastern region does not include Taiwan, the Hong Kong Special Administrative Region, and the Macao Special Administrative Region, and the western region does not include Tibet.

Table 4 Robustness test results

	lnCE (7)	lnCO$_2$ (8)	lnPGDP (9)	lnCE (7′)	lnCO$_2$ (8′)	lnPGDP (9′)
lnGI	0.2565** (2.328)	−0.0336 (−0.961)	0.0401*** (3.249)	1.4216*** (2.900)	−0.0211 (−0.646)	0.0496*** (2.987)
lnPGDP	−19.5*** (−4.171)	6.2561*** (7.794)		−92.15*** (−3.021)	7.729*** (10.005)	
lnPGDP^2	0.9115*** (4.088)	−0.2849*** (−7.032)		4.1313*** (2.889)	−0.371*** (−9.534)	
lnCE		0.2336*** (8.457)	−0.0208** (−2.472)			
lnCE^2			0.0025* (1.845)			0.0164 (1.502)
lnCO$_2$	0.7665*** (2.823)		0.0064 (0.323)	−7.289*** (−2.819)		−0.1819*** (−2.879)
cons	87.882*** (4.259)	−33.486*** (−7.579)	6.8449*** (32.146)	429.64*** (3.1)	−39.657*** (−9.387)	7.891*** (12.290)
Control variable	Control	Control	Control	Control	Control	Control
Time effect	Control	Control	Control	Control	Control	Control
Individual effect	Control	Control	Control	Control	Control	Control
chi2	294.47***	9370.44***	7220.63***	481.93***	9943.16***	22916.88***
R-square	−0.6229	0.9551	0.9494	0.0799	0.9557	0.9848

Note: in row lnCE, (9′) column contains −0.1536 (−1.601).

Table 5 Group analysis of heterogeneity

	Eastern city			Central city			Western city		
	lnCE (10)	lnCO$_2$ (11)	lnPGDP (12)	lnCE (13)	lnCO$_2$ (14)	lnPGDP (15)	lnCE (16)	lnCO$_2$ (17)	lnPGDP (18)
lnGI	6.026*** (2.586)	0.0401 (0.950)	0.0409* (1.923)	−0.969** (−2.450)	0.0836 (1.330)	0.056** (2.121)	0.423** (2.500)	0.711** (2.497)	0.1191** (2.554)
lnPGDP	−426.85** (−2.453)	13.84*** (3.536)		−71.48*** (−2.859)	6.8319* (1.780)		−38.57*** (−5.480)	−61.25*** (−2.525)	
lnPGDP^2	18.336*** (2.355)	−0.678*** (−3.695)		4.2917*** (3.361)	−0.413** (−2.208)		1.883*** (5.183)	2.90** (2.527)	
lnCE		−0.093*** (−3.169)	−0.08** (−2.029)		0.064* (1.676)	−0.2257** (−2.447)		−1.4*** (−3.336)	0.86*** (4.530)
lnCE^2			0.011** (2.433)			0.03*** (3.303)			−0.09*** (−4.890)
lnCO$_2$	−74.99*** (−2.587)		−0.23*** (−2.339)	10.801*** (6.227)		−0.447*** (−5.244)	−2.4404* (−1.647)		−0.644*** (−3.061)
cons	1363.3*** (2.257)	−69.81*** (−3.796)	6.51*** (13.111)	253.946** (2.104)	−23.6301 (−1.216)	10.58*** (16.235)	189.73*** (5.388)	297*** (2.608)	5.812*** (7.267)
Control variable	Control	Control	Control	Control	Control	Control	Control	Control	Control
chi2	68.28	7647.92	9884.41	370.61	2118.71	10428.07	1080.14	407.07	5790.42
R-square	−20.33	0.98	0.9859	−0.4318	0.9428	0.9885	0.8331	0.0902	0.9709

Presented here are the model results of Eastern China (11 provinces and cities), Central China (8 provinces and cities), and Western China (11 provinces and cities). A substantial difference can be observed in the level of economic development between the east and west of China. Columns (10), (13), and (16) are defined by the U-shaped relationship between clean energy consumption and economic growth in the eastern, central, and western regions; in the eastern (column 10) and western regions (column 16), green investment contributes to the consumption of green energy, and in the central region (column 13), green investment has a negative impact on the consumption of green energy; this is mainly because of the large scale of energy-intensive industries in the central energy and industrial provinces. Heavy industrial structures have resulted in highly concentrated energy consumption and pollution emissions, and transformations of the surrounding energy structure are resultingly more difficult. Although green investment had no significant effect on CO$_2$ emission reductions in the east (column 11) and central (column 14), it increased CO$_2$ emissions in the western region (column 17). Nonlinear relationships between clean energy consumption, CO$_2$ emissions, and economic growth were established in east, west, and central China. However, these results are not identical. Between economic growth and CO$_2$ emissions, the eastern region (column 11) and the central region (column 14) showed a significant "inverted U" curve, and the western region (column 17) demonstrated a "U" curve. Urban development slowed initially and then increased. The main reason for this result is that the development level of cities in the western region has been relatively low, and most of the western regions are resource-based cities (such as Shaanxi and Guizhou). In urban development, less CO$_2$ is emitted when economic development is slow. With the continuous development of the economy, a large loss of resources has caused serious environmental pollution, and other essential resources have not been accounted for over time. This has led to a slower improvement in the quality of urban development, and the area's limited technical level has caused more serious environmental pollution and resource depletion. Accordingly, carbon emissions have continued to increase.

In eastern cities, for every 1% increase in green investment in column (10), clean energy consumption increased by 6.026%. During the study period, economic growth developed to a certain stage only when the per capita GDP exceeded 113,500 (RMB) (lnPGDP = 11.6399). Energy use continued to increase, and CO$_2$ continued to decrease. Column (11) shows a significant inverted U-shaped relationship between CO$_2$ emissions and economic growth, which proves the existence of the environmental Kuznets curve. When the per capita GDP exceeded 42,000 (RMB) (lnPGDP=10.647), economic growth promoted a CO$_2$ emission reduction. The green investment, shown in column (12), was conducive to economic growth. For every 1% increase in green investment,

economic growth increased by 0.0409%. Comparing the empirical results of the eastern region as well as the entire country, the coefficient of 6.026 for green investment in the eastern region (column 10) on clean energy consumption is greater than that of the country (column 4) 1.9399 and higher than those of the central and western regions as well as the impact of green investment on CO_2. The emission coefficient was lower than that of the central and western regions, which also showed that the marginal role of the eastern region was increasingly obvious and that the efficiency increased. Compared with the national average level, the eastern region of China has a more complete environmental protection infrastructure, a higher concentration of talent, stronger technological innovation capabilities, and a more reasonable industrial structure. Therefore, the environmental benefits of green investments are most obvious in that region.

Conclusions and policy implications

Based on the environmental Kuznets curve theory and economic growth theory, this study used panel data from 30 provinces and cities in China from 2003 to 2017 and a simultaneous equation model to examine the impact of green investment on clean energy consumption and economic growth. The empirical results show that, first, from a national level, green investment has a significant positive impact on clean energy consumption and economic growth, although it has no significant effect on CO_2 emissions. There is a U-shaped relationship between economic growth and clean energy consumption, and there is an inverted U-shaped relationship between economic growth and CO_2 emissions, which verifies the EKC hypothesis to a certain extent. Second, the inflection point of clean energy use occurred earlier than the inflection point of CO_2 emissions. When the per capita GDP is greater than 105,735.93 (RMB), China's industrial, investment, technology, and energy structures undergo profound changes, entering a stage where technology-based enterprises are the mainstay. CO_2 emissions are reduced, and low consumption and low emissions are achieved through widespread clean energy use, thereby benefitting the environment. Third, considerable differences were observed in the impact of green investment on clean energy in the eastern, central, and western regions, and there are also differences in the nonlinear relationship between economic growth in the eastern, central, and western regions on clean energy consumption.

Through research, it is found that green investment has a positive effect on my country's clean energy consumption. The development of green investment can promote the low carbonization of energy consumption structures, but to fully come to fruition, it also requires the joint promotion of government policies, the financial industry,

and the environmental protection department. It is necessary to improve the investment policy of the environmental protection industry and the new energy industry while strengthening the implementation of quality effects. The two aspects, "emission reduction" and "energy saving," jointly promote the low-carbon energy consumption structure. Understanding the connection between government policies and green investment and strengthening the information disclosure policies of environmental protection departments and financial institutions are necessary to improve the feasibility of green investment.

Secondly, green investment should be made rationally according to local conditions. Green investment has a positive effect on my country's economic development. However, there are significant differences in the eastern, central, and western regions. Therefore, making full use of green investment to promote economic development must emphasize the principles of seeking truth from facts and adapting measures to local conditions. According to the economic development of various regions, corresponding policies should be formulated, and green investment should be made rationally to ensure the green, healthy, and efficient development of the economies of various cities.

Finally, to optimize the internal structure of green finance, the People's Bank of China can flexibly use various monetary policy tools, encourage various financial institutions to increase investment, and actively guide capital flows to increase support for the low-carbon development of energy consumption structures such as green credit and green securities. This will strengthen financial support for the environmental protection industry and new energy industry and promote my country's energy consumption structure to accelerate the process of low-carbon development.

Declarations

Ethical approval Not applicable.

Consent to participate   I am free to contact any of the people involved in the research to seek further clarification and information.

Consent for publication   Not applicable.

Competing interests   The authors declare no competing interests.

References

Adamantiades A, Kessides I (2009) Nuclear power for sustainable development: current status and future prospects. Energy Policy 37:5149–5166

Ahmed A, Uddin GS, Sohag K (2016) Biomass energy, technological progress and the environmental Kuznets curve: evidence from selected European countries. Biomass Bioenergy 90:202–208

Alam MM, Murad MW, Noman AHM, Ozturk I (2016) Relationships among carbon emissions, economic growth, energy consumption and population growth: testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia. Ecol Indic 70:466–479

Alkhathlan K, Javid M (2013) Energy consumption, carbon emissions and economic growth in Saudi Arabia: an aggregate and disaggregate analysis. Energy Policy 62:1525–1532

Al-mulali U (2014) Investigating the impact of nuclear energy consumption on GDP growth and CO_2 emission: a panel data analysis. Prog Nucl Energy 73:172–178

Apergis N, Payne JE (2010) Renewable energy consumption and growth in Eurasia. Energy Econ 32(6):1392–1397

Awodumi OB, Adewuyi AO (2020) The role of non-renewable energy consumption in economic growth and carbon emissions: evidence from oil-producing economies in Africa. Energy Strateg Rev 27:100434

Baek J, Kim H (2013) Is economic growth good or bad for the environment? Empirical evidence from Korea. Energy Econ 36:744–749

Bai Y, Song S, Jiao J, Yang R (2019) The impact of government R&D subsidies on green innovation: evidence from Chinese energy-intensive firms. J Clean Prod 233:819–829

Cai Y, Sam CY, Chang T (2018) Nexus between clean energy consumption, economic growth, and CO_2 emissions. J Clean Prod 182:1001–1011

Carraro C, Favero A, Massetti E (2012) Investments and public finance in a green, low carbon economy. Energy Econ 34:S15–S28

Chakraborty SK, Mazzanti M (2020) Energy intensity and clean energy innovation: Checking heterogeneous country effects in the OECD. Struct Chang Econ Dyn 52:328–343

Charfeddine L, Kahia M (2019) Impact of renewable energy consumption and financial development on CO_2 emissions and economic growth in the MENA region: a panel vector autoregressive (PVAR) analysis. Renew Energy 139:198–213

Chen Y, Ma Y (2021) Does green investment improve energy firm performance? Energy Policy 153:112252

Chontanawat J, Hunt LC, Pierce R (2008) Does energy consumption cause economic growth? Evidence from systematic study of over 100 countries. J Policy Model 30:209–220

Dinda S (2004) Environmental Kuznets curve hypothesis: a survey. Ecol Econ 49:431–455

Ding Y, Zhang M, Chen S, Wang W, Nie R (2019) The environmental Kuznets curve for PM 2.5 pollution in Beijing-Tianjin-Hebei region of China: a spatial panel data approach. J Clean Prod 220:984–994

Dong K, Sun R, Jiang H, Zeng X (2018) CO_2 emissions, economic growth, and the environmental Kuznets curve in China: what roles can nuclear energy and renewable energy play? J Clean Prod 196:51–63

Esteve V, Tamarit C (2012) Is there an environmental Kuznets curve for Spain? Fresh evidence from old data. Econ Model 29(6):2696–2703

Eyraud L, Clements B, Wane A (2013) Green investment: trends and determinants. Energy Policy 60:852–865

Grossman GM, Krueger AB (1994) Economic growth and the environment NBER. Working Paper No. 4634. National Bureau of Economic Research, Cambridge, UK

Gu Y, Ho K, Yan C, Gozgor G (2021) Public environmental concern, CEO turnover, and green investment: evidence from a quasi-natural experiment in China. Energy Econ 100:105379

Guo J, Zhou Y, Ali S, Shahzad U, Cui L (2021) Exploring the role of green innovation and investment in energy for environmental quality: an empirical appraisal from provincial data of China. J Environ Manag 292:112779

Hammoudeh S, Ajmi AN, Mokni K (2020) Relationship between green bonds and financial and environmental variables: a novel time-varying causality. Energy Econ 92:104941

He J, Richard P (2010) Environmental Kuznets curve for CO_2 in Canada. Ecol Econ 69(5):1083–1093

He L, Zhang L, Zhong Z, Wang D, Wang F (2019) Green credit, renewable energy investment, and green economy development: empirical analysis based on 150 listed companies in China. J Clean Prod 208:363–372

Heo J-Y, Yoo S-H, Kwak S-J (2011) The causal relationship between nuclear energy consumption and economic growth in India. Energy Sources, B 6(2):111–117

Ivanovski K, Hailemariam A, Smyth R (2021) The effect of renewable and non-renewable energy consumption on economic growth: non-parametric evidence. J Clean Prod 286:124956

Kahia M, Aïssa MSB, Charfeddine L (2016) Impact of renewable and non-renewable energy consumption on economic growth: new evidence from the MENA Net Oil Exporting Countries (NOECS). Energy 1161:102–115

Kang Y, Zhao T, Yang Y (2016) Environmental Kuznets curve for CO_2 emissions in China: a spatial panel data approach. Ecol Indic 63:231–239

Kanjilal K, Ghosh S (2013) Environmental Kuznets curve for India: evidence from tests for cointegration with unknown structural breaks. Energy Policy 56:509–515

Karásek J, Pavlica J (2016) Green investment scheme: experience and results in the Czech Republic. Energy Policy 90:121–130

Khan I, Hou F, Zakari A, Tawiah V (2021) The dynamic links among energy transitions, energy consumption, and sustainable economic growth: a novel framework for IEA countries. Energy 222:119935

King RG, Levine R (1993) Finance and growth: the Schumpeter might be right. Q J Econ 108(3):717–737

Lee JW (2013) The contribution of foreign direct investment to clean energy use, carbon emissions, and economic growth. Energy Policy 55:483–489

Li C, Gan Y (2021) Spatial spillover effects of green finance on ecological environment—empirical research based on spatial econometric models. Environ Sci Pollut Res Int 28(5):5651–5665

Liao X, Shi X (2018) Public appeal, environmental regulation and green investment: evidence from China. Energy Policy 119:554–562

Lin B, Moubarak M (2014) Renewable energy consumption and economic growth nexus for China Renew. Sustain Energy Rev 40(C):111–117

Liu Y, Dong F (2021) How technological innovation impacts urban green economy efficiency in emerging economies: a case study of 278 Chinese cities. Resour Conserv Recycl 169:105534

Liu X, Zhang X (2021) Industrial agglomeration, technological innovation, and carbon productivity: evidence from China. Resour Conserv Recycl 166:105330

Liu N, Liu C, Xia Y, Ren Y, Liang J (2020a) Examining the coordination between green finance and the green economy for sustainable development: a case study of China. Sustainability 12(9):3717

Liu X, Wang Z, Sun X, Zhang L, Zhang M (2020b) Clarifying the relationship among clean energy consumption, haze pollution, and economic growth, based on the empirical analysis of China's Yangtze River Delta region. Ecol Complex 44:100871

Musibau HO, Adedoyin FF, Shittu WO (2021) A quantile analysis of energy efficiency, green investment, and energy innovation in most industrialized nations. Environ Sci Pollut Res 28(15):19473–19484

Narayan PK, Narayan S (2010) Carbon dioxide emissions and economic growth: panel data from developing countries. Energy Policy 38(1): 661–666

Nasir M, Rehman F (2011) Environmental Kuznets curve for carbon emissions in Pakistan: an empirical investigation. Energy Policy 39(3):1857–1864

Omri A (2013) CO_2 emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models. Energy Econ 40(657):64

Ozturk I (2010) A literature survey on energy-growth nexus. Energy Policy 38:340–349

Pardo Martínez CI (2013) An analysis of eco-efficiency in energy use and CO_2 emissions in the Swedish service industries. Socio-Econ Plan Sci 47:120–130

Raghutla C, Shahbaz M, Chittedi KR, Jiao Z (2021) Financing clean energy projects: new empirical evidence from major investment countries. Renew Energy 169:231–241

Ren X, Shao Q, Zhong R (2020) Nexus between green finance, non-fossil energy use, and carbon intensity: empirical evidence from China based on a vector error correction model. J Clean Prod 277:122844

Roubini N, Sala-i-Martin X (1992) Financial repression and economic growth. J Dev Econ 39(1):5–30

Saboori B, Sulaiman J, Mohd S (2012) Economic growth and CO_2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. Energy Policy 51:184–191

Sebri M, Ben-Salha O (2014) On the causal dynamics between economic growth, renewable energy consumption, CO_2, emissions and trade openness: fresh evidence from BRICS countries. Renew Sust Energ Rev 39:14–23

Sephton P, Mann J (2013) Further evidence of an environmental Kuznets curve in Spain. Energy Econ 36:177–181

Shahbaz M, Lean HH, Shabbir MS (2012) Environmental Kuznets curve hypothesis in Pakistan: cointegration and granger causality. Renew Sust Energ Rev 16(5):2947–2953

Shahbaz M, Solarin SA, Mahmood H, Arouri M (2013) Does financial development reduce CO_2 emissions in Malaysian economy? A time series analysis. Econ Model 35:145–152

Shahbaz M, Van Hoang TH, Mahalik MK, Roubaud D (2017) Energy consumption, financial development and economic growth in India: new evidence from a non-linear and asymmetric analysis. Energy Econ 63:199–212

Shen Y et al (2021) Does green investment, financial development and natural resources rent limit carbon emissions? A provincial panel analysis of China. Sci Total Environ 755:142538

Song Y, Zhang M, Zhou M (2019) Study on the decoupling relationship between CO_2 emissions and economic development based on two-dimensional decoupling theory: a case between China and the United States. Ecol Indic 102:230–236

Soytas U, Sari R, Ewing BT (2007) Energy consumption, income, and carbon emissions in the United States. Ecol Econ 62(3–4):482–489

Sun Y, Li M, Zhang M, Khan HSUD, Li J, Li Z, Sun H, Zhu Y, Anaba OA (2021) A study on China's economic growth, clean energy technology, and carbon emissions based on the Kuznets curve (EKC). Environ Sci Pollut Res Int 28(6):7200–7211

Tolliver C, Keeley AR, Managi S (2020) Policy targets behind green bonds for renewable energy: do climate commitments matter? Technol Forecasting Soc Change 157:120051

Wang Q, Wang L (2020) Renewable energy consumption and economic growth in OECD countries: a nonlinear panel data analysis. Energy 207:118200

Wang Y, Zhi Q (2016) The role of green finance in environmental protection: two aspects of market mechanism and policies. Energy Procedia 104:311–316

Wolde-Rufael Y (2010) Bounds test approach to cointegration and causality between nuclear energy consumption and economic growth in India. Energy Policy 38(1):52–58

Xu Q, Lei Y, Ge J, Ma X (2017) Did investment become green in China? Evidence from a sectoral panel analysis from 2003 to 2012. J Clean Prod 156:500–506

Yoo SH, Jung KO (2005) Nuclear energy consumption and economic growth in Korea. Prog Nucl Energy 46(2):101–109

York R, Bell SE (2019) Energy transitions or additions?: Why a transition from fossil fuels requires more than the growth of renewable energy. Energy Res Soc Sci 51:40–43

Zahan I, Chuanmin Shuai, 2021. Towards a green economic policy framework in China: role of green investment in fostering clean energy consumption and environmental sustainability. Environmental Science and Pollution Research

Zhang M, Liu XX, Sun XR, Wang WW (2020a) The influence of multiple environmental regulations on haze pollution: evidence from China. Atmos Pollut Res 11:170–179

Zhang M, Li H, Su B, Yang X (2020b) Using a new two-dimensional decoupling model to evaluate the decoupling state of global energy footprint. Sustain Cities Soc 63:102461

Zhou A, Li J (2019) Heterogeneous role of renewable energy consumption in economic growth and emissions reduction: evidence from a panel quantile regression. Environ Sci Pollut Control Ser 26(22): 22575–22595

Zhou X, Tang X, Zhang R (2020) Impact of green finance on economic development and environmental quality: a study based on provincial panel data from China. Environ Sci Pollut Res Int 27(16):19915–19932

Zhu H, Zheng J, Zhao Q, Kou D (2020) Economic growth, energy structure transformation and carbon dioxide emissions-empirical analysis based on panel data. Research on Economics and Management 41: 19–34