Clarifying the Relationship Among Green Investment, Clean Energy Consumption, Carbon Emissions, and Economic Growth: A Provincial Panel Analysis of China

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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: Green investment considers energy conservation and environmental protection as its main goals. Few studies based on simultaneous equation models have evaluated the relationships 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 establish a simultaneous equation model that can evaluate these crucial relationships. At the national level, green investment has a significantly positive impact on clean energy consumption and economic growth; however, it has no significant effect on carbon dioxide emissions. Moreover, there is a U-shaped relationship between economic growth and clean energy consumption, as well as economic growth and CO2 emissions. When the per capita GDP is greater than 105735.92 (RMB), the use of clean energy will increase and CO2 emissions will decrease, thereby benefitting the environment and economy. Additionally, the impacts of green investment on clean energy differ in China’s eastern, central, and western regions, and the non-linear relationships between economic growth and clean energy consumption in these regions also differ. Based on these findings, countermeasures and suggestions are proposed to spur development within different regions.

Keywords Green investment. Clean energy. Economic development. Simultaneous Equation Model. carbon emissions.

Declarations

This manuscript does not report on or involve the use of any animal or human data or tissue, so it’s not applicable. It has not been published or presented elsewhere in part or in entirety and is not under consideration by another journal. We have read and understood your journal’s policies, and we believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare. All data generated or analysed during this study are included in its supplementary information files. This work was supported by Guangzhou City Philosophy and Social Science Planning 2019 Project (no.2019GZGJ221). Y. Wan, who collected the data and wrote the entire paper, was a major contributor to the manuscript, and N. Sheng made adjustments to the structure and framework of the entire paper. All authors read and approved the final manuscript. We would like to appreciate the anonymous reviewers for their valuable comments.

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.
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 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, CO2 emissions, PGDP, and
environmental protection investments are discussed in the following paragraph.

Figure 1 shows that the composition of China’s energy consumption from 2000 to 2017 is dominated by coal. 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 CO2 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 2000–2017. 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).

Literature Review, and Hypotheses

Green investment, economic growth, clean energy consumption, and CO2 emissions are currently the primary foci of research in the field of environmental economics at home and abroad. The main research content is divided into the following three
2.1 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 21st 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, 2012). Green investment may also be aimed at reducing greenhouse gas emissions and promoting policies and programs to protect the environment and climate.

2.2 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 et al. (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.

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; 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.

2.3 Relationship between green investment and CO2 emissions

**Hypothesis 3:** Green investment has a significant effect on reducing CO2 emissions.

At present, some studies have concluded that financial support can range from increasing to suppressing CO2 emissions, or they may have no effect whatsoever. Shen et al. (2020) 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 CO2. Green investment is negatively correlated with CO2, 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. (2020) noted that foreign direct investment inflows had a significantly negative impact on CO2 emissions. However, green investment had no significant effect on CO2 emissions. Hammoudeh et al. (2020) examined green bonds and other assets (including U.S. conventional bonds). They observed a time-varying causal relationship between the Seoul clean energy (stock) index and the price of CO2 emission allowances. Moreover, their recursive evolution causality algorithm showed that the causality relationship between the clean energy index and green bonds with CO2 emissions was not significant. Charfeddine and Kahia (2019) revealed that financial development had no significant impact on effectively mitigating CO2 emissions in the Middle East and North Africa.

2.4 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; 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 (2010b), 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.

Others have recognized the possibility of a non-linear relationship between energy consumption and economic growth. (Wang, Q. and L. 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 non-linear effect on promoting economic development. Zhou (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; Shahbaz et al., 2017) also used the nonlinear ARDL method to study the nonlinear effects of economic growth and carbon emissions.

2.5 Relationship between economic growth and CO2 emissions

Hypothesis 5: Economic growth has a nonlinear impact on CO2 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 (2012a), Baek and Kim (2013), Kanjilal and Ghosh (2013), Nasir and Ur Rehman (2011), Sabori et al. (2012), Sephton and Mann (2013), and Shahbaz et al. (2015) studied the economic growth of Canada, Spain, South Korea, India, Pakistan, Malaysia, and Portugal, respectively, and their inverted U-shaped relationship between CO2, which is in accordance with the environment. Alam et al. (2016) verified that Indonesia, China, and Brazil have statistically significant per capita CO2 emissions and that their per capita real GDP values show an inverted U-shaped relationship. Moreover, the carbon pools of Indonesia, China, and Brazil via the Znets curve, although India showed a positive U-shaped relationship (Narayan and Narayan 2010). Based on empirical research in Iraq, Jordan, Kuwait, Yemen, Qatar, the UAE, Argentina, Mexico, Venezuela, Algeria, PK, Kenya, Nigeria, Congo, Ghana, and South Africa, CO2 emissions have reduced over time. Long-term income elasticity is less than the short-term income elasticity, and nations reduce their emissions as income increases. Soytas et al. (2007) studied the relationship between GDP and CO2 in the United States from 1960 to 2004 and found that it did not conform to the EKC curve.

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 CO2 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 ten
years. At present, there is no research on the interactive development of special
green investments, clean energy consumption, and carbon emissions in China and the
world. The contributions of this study are as follows: first, clean energy
consumption and economic growth are listed as important variables in addition to
green investments and carbon emissions. The four variables are placed in a unified
analysis framework to empirically analyze the impact of green finance on China’s
economic development and green energy. To ensure that multiple relationships are
considered between the four studied variables, and to avoid estimation bias, a panel
simultaneous equation model is used to overcome the shortcomings of the above
literature. Second, to ensure that more than simply linear relationships between
economic variables are considered, this study re-examines the relationship between
green investment, clean energy consumption, CO2 emissions, and economic growth.
Economic phenomena are complex and changeable, leading to relationships between
economic variables, and there are often numerous nonlinear relationships. Thus, to
improve the robustness of this study’s results, findings have been grouped by
China’s eastern, central, and western regions. The results of this study can be
used to ensure the future development of clean energy consumption and green
investment in a healthier and more sustainable manner as well as provide a reference
for the formulation of relevant policies and measures. Finally, this study further
examines the specific forms and turning points of economic growth on clean energy
and CO2 emissions.

**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 were calculated based
on the database of the National Bureau of Statistics, the “China Energy Statistics
Yearbook,” the “China Science and Technology Statistics Yearbook,” the “China
Statistics Yearbook” and the “China Environment Statistics Yearbook.” The following
consists of a broad categorization of these data:

1. Green investment (GI): reflects the proportion of GDP that is recovered
through investing in environmental pollution control efforts (Liao, X. and X.R. Shi,
2018): Compared with traditional investment, the largest difference between green
investment and traditional investment is how the two models address the relationship
between economic growth and environmental protection, which is mainly related to
the backgrounds in which they are produced. The traditional investment model
originated from the established extensive production model; this approach focused
only on economic benefits and did not account for the discharging of pollutants into
nature, thereby ignoring environmental protection and sustainable development.
Given the increasingly intensified contradictory relationship between economic
growth and environmental pollution, simultaneously ensuring the economic and
environmental benefits of investment has become a problem that all investment
entities must consider. Green investment has emerged at a historic moment, and has highlighted the differences in goals between these two investment models.

(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 CO2. 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, Y. and F. D., 2020). 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) CO2 emissions: China’s CO2 emissions data were extracted from the official website of China’s emissions accounts and datasets (CEADs; http://www.ceads.net/).

(4) Economic growth: Expressed in real GDP per capita (Wang, Q. and L. 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.

Control variables

Combining existing research with our previous discussions, we also controlled a set of urban characteristic variables in the simultaneous equation regression model to minimize the errors of variable omissions as follows:

(1) Technological Innovation (TECH): This variable is expressed by the number of technological patent applications granted by provinces and cities (Bai, Y. et al., 2019; Liu, X., Zhang, X., 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, X. and X.R. 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, M. et al., 2020; Liu, X., et al. 2020). 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. (2020) 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., 2020; 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 CO2 emissions.

(8) Proportion of coal consumption structure (COAL consumption) 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., 2020).

Table 1 Descriptive statistics table

| Variable   | Obs | Mean   | Std. Dev. | Min   | Max   |
|------------|-----|--------|-----------|-------|-------|
| lnPGDP     | 450 | 10.2341| 0.7214    | 8.2164| 11.7675|
| lnCE       | 450 | 4.7117 | 1.7674    | -2.1203| 8.0378|
Econometric method

Equation (1) studies the impact of green investment, economic growth, CO2, 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 CO2 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. The control variable V includes the ER, STR, PEDU, 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 CO2 on economic growth. Equation (6) considers the primary and secondary terms of clean energy consumption to analyze the possible non-linear 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 CO2 emissions are as follows: green investment will affect clean energy development, CO2 emissions, and economic growth. Moreover, clean energy development and CO2 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., 2020). Therefore, we have established a simultaneous equation composed of regression models in which green investment, clean energy development, CO2 emissions, and

| Variable | Coefficient 1 | Coefficient 2 | Coefficient 3 | Coefficient 4 |
|----------|---------------|---------------|---------------|---------------|
| lnCO2    | 5.3502        | 0.8436        | 2.0222        | 7.3473        |
| lnGI     | 4.7558        | 1.0738        | 1.2809        | 7.2557        |
| lnTECH   | 0.4208        | 1.6482        | -4.3901       | 4.1397        |
| lnSTR    | -0.8763       | 0.1828        | -1.2235       | -0.2157       |
| lnFDI    | 3.1371        | 1.6765        | -1.9005       | 5.8794        |
| lnURB    | 5.3127        | 1.4481        | 0.8467        | 7.9875        |
| lnCOAL   | -0.1286       | 0.4200        | -2.6771       | 0.7613        |
| lnER     | -5.9054       | 0.7148        | -8.1398       | -3.8263       |
| lnPEDU   | 7.1748        | 0.6967        | 5.5075        | 8.6595        |
| lnTRAN   | -5.9568       | 0.6427        | -7.9096       | -4.3037       |
economic growth are explained variables, where GE represents clean energy consumption, greeninv represents green investment, and CO2 represents CO2 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:
\[
\begin{align*}
GE_i &= \tilde{\beta}_0 + \tilde{\gamma}_1 GI_i + \tilde{\gamma}_2 PGDP_i + \tilde{\gamma}_3 CO_2 + \delta U + \theta_i + \nu_i + \epsilon_{it} \\
CO_2 &= \beta_0 + \beta_1 GI_i + \beta_2 PGDP_i + \beta_3 GE_i + \delta V + \theta_i + \nu_i + \epsilon_{it} \\
PGDP_i &= \gamma_0 + \gamma_1 GI_i + \gamma_2 PGDP_i + \gamma_3 CO_2 + \delta W + \theta_i + \nu_i + \epsilon_{it}
\end{align*}
\]

The quadratic model:
\[
\begin{align*}
GE_i &= \tilde{\beta}_0 + \tilde{\gamma}_1 GI_i + \tilde{\gamma}_2 PGDP_i + \tilde{\gamma}_3 PGDP^2_i + \tilde{\gamma}_4 CO_2 + \delta U + \theta_i + \nu_i + \epsilon_{it} \\
CO_2 &= \beta_0 + \beta_1 GI_i + \beta_2 PGDP_i + \beta_3 PGDP^2_i + \beta_4 GE_i + \delta V + \theta_i + \nu_i + \epsilon_{it} \\
PGDP_i &= \gamma_0 + \gamma_1 GI_i + \gamma_2 GE_i + \gamma_3 GE^2_i + \gamma_4 CO_2 + \delta W + \theta_i + \nu_i + \epsilon_{it}
\end{align*}
\]

Table 2 Basic estimation results of the simultaneous equation model

|                | Linear model          | Quadratic model        |
|----------------|-----------------------|------------------------|
|                | lnCE                  | lnCO2                  | lnPGDP | lnCE     | lnCO2     | lnPGDP   |
| lnGI           | 0.1094                | 0.0078                 | 0.0285  | 1.9399***| -0.0404***| 0.0701***|
|                | (0.169)               | (0.148)                | (0.779) | (3.121)  | (-1.190)  | (3.378)  |
| lnPGDP         | -3.4471               | 1.0606***              | -114.653| 5.8908***|           |          |
|                | (-0.616)              | (4.088)                |         |          |           |          |
| lnPGDP^2       | 5.3544***             | -0.2546***             |         |          |           |          |
|                | (3.451)               | (-7.236)               |         |          |           |          |
| lnCE           | 0.3756**              | 0.0021                 | 0.0417**| 0.2126*  |           |          |
|                | (1.991)               | (0.067)                | (1.978) | (1.924)  |           |          |
| lnCE^2         | -0.0234*              |                       |         |          |           |          |
|                | (-1.866)              |                       |         |          |           |          |
| lnCO2          | 1.2578                | 0.4028*                | -9.0606***| 0.0775 |          |          |
|                | (0.182)               | (1.835)                | (-3.352)| (1.379)  |           |          |
| lnSTR          | 0.0146                |                       | 5.5505***| 7.8872**|           |          |
|                | (0.008)               |                       | (2.869) | (2.003)  |           |          |
| lnER           | 0.0190                | -0.0062                | -0.3994 | 0.0594***| -0.0794***|          |
|                | (0.095)               | (-0.144)               | (-1.530)| (3.043)  | (-3.556)  |          |
| lnCOAL         | 0.0496                | 0.2316                 | 5.0209***|  |           |          |
|                | (0.015)               | (1.614)                | (3.058) |           |           |          |
| lnPEDU         | 0.8750                | 0.2314                 | 18.3982***| 0.5398***|           |          |
|                | (0.197)               | (1.610)                | (3.578) | (6.409)  |           |          |
| lnURB          | 0.0261                | 0.0128                 | 0.9625**| 0.0352*  |           |          |
|                | (0.102)               | (0.968)                | (2.209) | (1.681)  |           |          |
\[
\begin{array}{cccc}
\text{lnTRAN} & & & -0.6173^{***} \\
\text{lnFDI} & -0.0010 & -0.0418^{**} \\
& (-0.134) & (-2.185) \\
\text{cons} & 23.3066 & 23.3066 & 23.3066 \\
& (0.531) & (-2.384) & (-8.542) \\
\text{chi2} & 2332.2 & 4321.79 & 6217.98 \\
& 9914.72 & 21765.78 \\
\text{R-square} & 0.8725 & 0.8986 & 0.9337 \\
& 0.9580 & 0.9770 \\
\end{array}
\]

### Results and Discussion

Table 2 reports the estimated results of the simultaneous equations. Columns (1)-(3) consider the linear relationship among green investment, clean energy consumption, CO2 emissions, and economic growth. Column (1): in the clean energy equation, investment, CO2, and economic growth have no significant impact on the consumption of green energy. Column (2): in the CO2 equation, clean energy use and economic growth will increase CO2 emissions, and green investment has no significant impact on CO2 emissions. Column (3): in the economic growth equation, green investment and clean energy consumption have no significant impact on economic growth, and the increase in CO2 emissions promotes economic growth.

Further considering the non-linear effects between the key variables in this study, columns (4)-(6) represent the corresponding estimation results. The green investment in column (4) is positive (significant at the 1% level), thereby indicating that as green investment increased, regions increasingly used green energy. Green investment had a positive impact on clean energy consumption, and thus hypothesis 1 is verified. Additionally, clean energy consumption increased by 0.5295%, and the primary and secondary terms of GDP per capita were significantly negative and positive, respectively, which indicated that there is a significant U-shaped relationship between clean energy consumption and economic growth. Hypothesis 4 was verified only for when a city’s economy developed to having a per capita GDP exceeding 44,600 (RMB) (lnPGDP = 10.706) during the study period. In this scenario, economic growth can promote the transformation of the energy structure and increase the use of green energy. During the study period, when the per capita GDP was below 44,600 (RMB), economic development did not accelerate the use of green energy. The estimated coefficient of CO2 emissions was significantly negative, which indicated that the increase in CO2 emissions in a certain area hindered the development of green energy. In column (5), the coefficient of CO2 corresponding to green investment was negative. The degree of development of green investment reduced CO2 emissions; however, the impact was not significant. Therefore, hypothesis 2 was not valid. The possible reason for this result was that some companies may have paid excessive attention to the concept of green investment. The low-carbon environmental protection industry has good profitability and growth, but its risks are relatively high, and energy savings and emission reductions are not substantial. Activities that provide financial support for green development and
carbon emission reduction require the strong promotion and guidance of a green
financial supply from the government and its associated policies. In addition, the
primary and secondary terms of per capita GDP were significantly positive and
negative, respectively, which confirmed the existence of EKC (Sun, Y. et al., 2021)
for CO2 emissions and validated hypothesis 5. Specifically, CO2 emissions and
economic growth showed a significant inverted U-shaped relationship. When the per
capita GDP exceeded 105,700 (RMB) (lnPGDP =11.5687), economic growth promoted CO2
emission reductions.

In addition, the estimated coefficient of clean energy consumption was
significantly positive, which means that, on average, clean energy consumption does
not significantly reduce CO2 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.

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 (Zhu et al. 2020), and the relationship between economic
growth and CO2 is an inverted U-shape (Alam et al., 2016; Dong, K. 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 pre-industrial economies, 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 CO2 emissions increase. When the per capita
GDP is between 44,600 and 105,700 (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
CO2 emissions remain high. During the emission phase, the energy structure
constantly transforms and is upgraded. When the per capita GDP is greater than
105,700 (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. CO2 emissions are reduced, energy consumption and
industrial emissions are reduced, the industrial base becomes advanced, and clean
energy production greatly increases, introducing a win-win scenario.
Figure 2. Relationship between economic growth, clean energy and carbon dioxide
Source Md. Mahmudul Alam et al. (2016)

Robustness test

We further evaluated the robustness of the model to obtain reliable estimation results. First, the core explanatory variables were processed with a one-period lag considering the time lag of the impact of various economic variables. Table 3 presents the corresponding estimation results. The signs and significance of the core variables remain essentially unchanged. Certain interactions were observed between green investment, green energy, carbon emissions, and economic development. Fortunately, the estimated results of these interactions were consistent. For example, green investment increased the use of clean energy and contributed to economic growth, but did not significantly reduce CO2 emissions. Concurrently, a non-linear relationship between economic growth and clean energy and CO2 was established. These results further proved the robustness of the regression results in this study.

Table 3: Robustness test results

|     | lnCE   | lnCO2  | lnPGDP   |
|-----|--------|--------|----------|
| (7) |        |        |          |
| lnGI| 0.2565* | -0.0336 | 0.0401*** |
|     | (2.328) | (-0.961) | (3.249)   |
| lnPGDP| -19.5013*** | 6.2561*** |          |
|     | (-4.171) | (7.794)  |          |
| lnPGDP^2 | 0.9115*** | -0.2849*** |          |
|     | (4.088)  | (-7.032) |          |
| lnCE |        |        |          |
|     | 0.2336*** | -0.0208** |          |
|     | (8.457)  | (-2.472) |          |
| lnCE^2 |        |        |          |
|     |        |        | 0.0025*  |
|     |        |        | (1.845)  |
| lnCO2| 0.7665*** |    0.0064 |          |
|     | (2.823)  |          | (0.323)  |
Table 4 provides a group analysis of the heterogeneity of the studied variables within the grouped regions of the study area (Chakraborty and Mazzanti, 2020; Zhou, A., Li, J., 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, 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 Group analysis of heterogeneity

| Variable | Eastern city | Central city | Western city |
|----------|--------------|--------------|--------------|
| lnCE | lnCO2 | lnPGDP | lnCE | lnCO2 | lnPGDP | lnCE | lnCO2 | lnPGDP |
| (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
| lnGI | 6.026*** | 0.0401 | -0.969*** | 0.0830 | 0.056** | 0.423** | 0.711** | 0.1191** |
| (2.586) | (0.950) | (-2.450) | (1.330) | (2.121) | (2.500) | (2.497) | (2.554) |
| lnPGDP | -426.85*** | 13.84*** | -71.48*** | 6.8319* | -38.57*** | -61.25** |
| (2.453) | (3.536) | (-2.859) | (1.780) | (-5.480) | (-2.525) |
| lnPGDP² | 18.336** | -0.678*** | -4.2917*** | -0.413** | 1.883*** | 2.90** |
| (2.355) | (-3.695) | (3.361) | (-2.208) | (1.813) | (2.527) |
| lnCE | -0.093*** | -0.08** | 0.064* | -0.2257** | -1.4*** | 0.86*** |
| (3.169) | (-2.029) | (1.676) | (-2.447) | (-3.336) | (4.530) |
| lnCE² | 0.011** | 0.03*** | 0.09*** |
| (2.433) | (3.303) | (-4.890) |
| lnCO2 | -74.99*** | -0.2301* | 10.801*** | -0.447*** | -2.4404* | -0.644*** |
| (2.587) | (-2.339) | (6.227) | (-5.244) | (-1.647) | (-3.061) |
| cons | 1363.3*** | -69.81*** | 6.5082*** | 253.946*** | -23.6301 | 10.58*** | 189.73*** | 297*** | 5.812*** |
| (2.257) | (-3.796) | (13.111) | (2.104) | (-1.216) | (16.235) | (5.388) | (2.608) | (7.267) |
| Control variable | 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 |
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 resulting more difficult. Although green investment had no significant effect on CO2 emission reductions in the east (column 11) and central (column 14), it increased CO2 emissions in the western region (column 17). Non-linear relationships between clean energy consumption, CO2 emissions, and economic growth were established in east, west, and central China. However, These results are not identical. Between economic growth and CO2 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 CO2 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) \((\ln \text{PGDP} = 11.6399)\). Energy use continued to increase, and CO2 continued to decrease. Column (11) shows a significant inverted U-shaped relationship between CO2 emissions and economic growth, which proves the existence of the environmental Kuznets curve. When the per capita GDP exceeded 42,000 (RMB) \((\ln \text{PGDP} = 10.647)\), economic growth promoted a CO2 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 CO2. 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 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 CO2 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 CO2 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 CO2 emissions. When the per capita GDP is greater than 105,700 (RMB), China’s industrial, investment, technology, and energy structures undergo profound changes, entering a stage where technology-based enterprises are the mainstay. CO2 emissions are reduced, low consumption and low emissions are achieved through widespread clean energy use, thereby benefitting both the environment and. 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.

Suggestions

Our first suggestion is for China to speed its transition to green energy. China has built the world’s largest clean energy system, which will promote clean, low-carbon, safe, and efficient energy usage, accelerate the development of new energy, offer environmental protection, and promote a comprehensive green transformation for economic and social development. To revolutionize the supply of clean and low-carbon energy, a national low-carbon emission standard should be adopted. Additionally, fossil fuels should be replaced, thereby improving the country’s energy self-sufficiency and promoting energy security. To further change energy consumption patterns, China should accelerate the electrification of terminal energy, promote energy diversification, and improve energy efficiency and energy quality. It is also necessary to accelerate the construction of a new technology system with a high proportion of new energy and a higher level of electrification. Finally, energy system reforms should continue to be implemented, and the modern market system for energy and power must be constantly improved to fully demonstrate its capabilities.

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Figures

**Figure 1**

Primary energy mix and CO2 emissions from 2000 to 2017 in China. Data source: BP, 2018; CSY, 2018.

**Figure 2**


Relationship between economic growth, clean energy and carbon dioxide Source Md. Mahmudul Alam et.al(2016)

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