



Can CO₂ Emission Reduction and Economic Growth Be Compatible? Evidence From China

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The influence of low-carbon energy on economic development is a vital issue. Using the provincial panel data in China from 2000 to 2017, this work investigated the aggregate effects of low-emission electricity. The results showed that 1) when the ratio of low-emission electricity to total electricity increases by 1%, the GDP per capita will increase by 0.16% and CO₂ emissions will decrease by 0.848%. In other words, low-emission electricity can achieve the goal of low-carbon economic development; 2) the self-supply of low-emission electricity, rather than trade and efficiency, is the main reason for China's boosted economic growth; and 3) low-emission electricity increases the regional economic gap in China. The effects of pollution inhibition and economic promotion on low-emission electricity in developed areas are significantly greater than those in less developed areas. Thus, the low-emission electricity policy in China should benefit the economy and avoid the excessive economic gap among regions. Policymakers should vigorously promote the low-emission electricity revolution and pay attention to the inclination of energy policy to the central and western regions.

Keywords: low-emission energy, CO₂ emissions, economic growth, regional heterogeneity, balance of development

INTRODUCTION

The 2015 Paris Climate Conference claimed that, in this century, the global temperature rise should be brought to 2°C lower than that before industrialization and ideally should be below 1.5°C (UNFCCC, 2015; Azam et al., 2020; Duan et al., 2021). For its ambitious aim, China's CO₂ emissions and energy consumption should be reduced by more than 90 and 39%, respectively, and China's cumulative policy costs may reach 2.8–5.7% of its GDP in 2050 (Duan et al., 2021). Duan et al. (2021) implied that the goal of CO₂ emission reduction and economic growth may be hard to coordinate due to the enormous costs.

Is it tough for CO₂ emission reduction to be compatible with the goal of economic growth¹? Furthermore, what are the possible reasons? In response to Duan et al. (2021), we try to offer some

¹We also recognize that COVID-19 caused uncertainty in economic growth and the contribution of energy to economic growth may be uncertain. Some studies suggested that energy, especially new energy, contributes to economic growth (Magazzino et al., 2021; Azam et al., 2020). However, there are also studies showing that energy had a negative impact on economic growth. For example, Garcia1 et al. (2020) believed that peak oil production will lead to economic contraction. The article gives compelling evidence that between 2000 and 2017 increasing the proportion of LEE in the energy mix contributed to economic growth and reduced CO₂ emissions in some regions of China.

details on the effects of low-emission electricity (LEE) on CO₂ emission reduction and economic growth. In this article, by employing the clean electricity consumption data of China, we give evidence supporting an answer to the following questions: 1) Can LEE be beneficial to CO₂ emission reduction and economic growth? 2) What are the possible mechanisms of LEE on economic development and CO₂ emissions? 3) Does the development of LEE in an economically disadvantaged region lead to the difference in regional economic growth?

What we were facing is a paradox. On the one hand, we know the adverse effects of greenhouse gas emissions caused by burning fossil energy on ecosystem activities. On the other hand, energy is an essential engine of economic development, which affects our essential well-being (Mendonç et al., 2020). The novel coronavirus pandemic has had a great impact on the global economy, and the demand for almost all energy products has dropped sharply. However, these negative effects are expected to recover in the short term, and the global energy demand is expected to rise in 2025 (IEA, 2020). Simultaneously, CO₂ emissions have increased from 205.18 million tons in 1990 to 32.314 billion tons in 2016 due to fossil fuel consumption and agriculture (IEA, 2018²).

Electricity is an integral part of modern energy and plays an essential role in economic growth (Das et al., 2012; Hamida, 2012; Tang and Tan, 2012; Mahfoudh and Amar, 2014). Of course, the acquisition of electricity mostly depends on the transformation of traditional energy (such as fossil fuel). Similar to other fuel-oil energy, electricity consumption faces the contradiction between economic development and environmental protection. Fortunately, this does not constitute an irreconcilable contradiction. Recent studies demonstrated that the application of renewable energy had decreased CO₂ emissions (Toumi and Toumi, 2019; Cosmas et al., 2019; Azam et al., 2020). Hydropower- and nuclear-related technologies have similar effects as well (Noorpoor and Kudahi, 2015). Unfortunately, not all countries or regions have enough economic or technological strength to produce electricity.

The electricity production of the world's highest income countries accounts for almost 70% of the world's electricity production (BPstats, 2018). The United States and European electric power consumption increased until 2007. Since then, their consumption has been slightly down (BPstats, 2018). From the perspective of electric technology, developed countries such as the United States, Canada, and Japan rely on coal energy less than 35%, while developing countries such as China and India rely on coal energy more than 60%. There is not enough data for third-world countries such as the sub-Saharan countries. As a representative sub-Saharan country, however, South Africa relies on coal energy as high as 87.73% for total electricity production. He et al. (2019) also reported that CO₂ emissions in the sub-Saharan region based on fossil fuel were severe.

The development of electricity is unbalanced not only in the world but also within countries. In China, the capacity for developing LEE varies in different regions. For example, northwest China has a vast territory, short rainy seasons, and sufficient light. It has the natural advantage of developing solar energy, wind energy, and biogas. The limitations for these regions are that there are not enough capital and technical advantages. China's coastal cities have certain technological advantages and can also develop geothermal energy and nuclear energy. For that of China's central region, the comparative advantages are not outstanding. China's overall level of LEE is constantly improving. For example, the proportion of clean electricity increased from 11.8% in 2013 to 17.4% in 2017, but compared with 66% proposed by Duan et al. (2021), China still needs to make great efforts for clean electricity development.

To our knowledge, current studies care more about the effects of LEE among different countries (Ozturk, 2010; Polemis and Dagoumas, 2013; Alper and Oguz, 2016) or within a country (Lee and Chang, 2005; Ho and Siu, 2007; Ang, 2008; Karanfil, 2008; Zhang and Cheng, 2009). Nevertheless, few pay attention to the heterogeneous effects of LEE on CO₂ emission reduction and economic growth in a country with unbalanced development. So, this work investigates the comprehensive effects of clean electricity based on the provincial panel data in China from 2000 to 2017. We found that 1) LEE development contributes to economic growth and carbon emission reduction, and its driving mechanism is internal LEE supply; 2) there are great differences in the impacts of LEE development among the three different regions of China; and 3) from 2000 to 2017, China's LFE to economic growth and carbon emission reduction is increasingly significant.

The conclusions of this article is a response to the questions of Duan et al. (2021) on China's energy cost pressure, and this study further offers a valuable paradigm for analyzing the LEE policy of countries with unbalanced economic development. The remainder of this article is arranged as follows. The second part introduces the literature review; the third part is the research design; the fourth part is the empirical analysis, which introduces the relationships among LEE, economic growth, and CO₂ emissions; and the last part is the discussions and conclusions.

LITERATURE REVIEW

Discussion on the relationship between LEE, CO₂ emissions, and economic growth is rare, while the research studies that involved energy and CO₂ emissions have been relatively old. Although there are many inconsistencies in the current conclusions, they provide rich theoretical support for understanding the relationship between LEE, CO₂ emissions, and economic growth. The pairwise correlation variables between the primary studies will be discussed in this section.

Energy and Economic Growth

Energy can be the power support of production and can partly replace capital or labor input. So, it is considered one of the

²According to the EPA (<https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data>) 24% of greenhouse gas emissions come from land use, while all transportation accounts for only 14%.

significant reasons for promoting economic growth (Ozturk, 2010). Previous studies focus on the causality between traditional electricity consumption and economic growth using various methods, but the results are always different. Some literature found that energy can promote economic growth unidirectionally (Lee and Chang, 2005; Ho & Siu, 2007; Karanfil, 2008). Some demonstrated that economic growth can promote energy use unidirectionally (Ang, 2008; Zhang and Cheng, 2009). At the same time, some others implied that the relationships between economic growth and energy use can be bidirectional (Polemis and Dagoumas, 2013; Ohler and Fetters, 2014). Some researchers showed no relationship between economic development and energy use (Payne, 2009; Menyah and Wolde-Rufael, 2010). In summary, the relationship between energy and economic growth is complex, and the situations vary significantly in different countries (Alper and Oguz, 2016; Ozturk, 2010).

Compared with fossil fuels, LEE is useful for its low carbon emission and renewability. Studies show relevant evidence for the effects of LEE on economic growth. Based on the data from South Korea, Yoo and Jung (2005) found the effects of nuclear energy on economic growth in the short and long terms. Heo et al. (2011) and Wolde-Rufael (2012) also found similar conclusions. Recently, the relationships between LEE and GDP have been exploited in numerous methods. For example, Azam et al. (2020) tried to figure out the impact of natural gas, nuclear energy, and renewable energy on CO₂ emissions and economics. They found that the tasks of CO₂ emission reduction and economic growth could be more compatible in nuclear and renewable energy. Magazzino et al. (2021) used machine learning to predict the future changes in CO₂ in China, India, and the United States. They believe that renewable energy is a vital factor for the decline of CO₂ in China and the United States. Abbas et al. (2020) found that renewable energy can help sustain environmental conditions without affecting economic growth among the “Belt and Road” countries.

However, dispute about the causal relationship between nuclear energy consumption and economic growth also exists. For example, national differences may affect the effect of nuclear energy on economic growth (Menyah and Wolde-Rufael, 2010; Chang et al., 2014). Their long-term and short-term single causal relationships may not be stable (Apergis and Payne, 2010).

Energy and CO₂ Emissions

Numerous previous studies focused on the long-term relationships between economic growth and energy consumption. Energy consumption relying on burning fossil fuels causes greenhouse gas emissions, leading to climate change and environmental degradation (Ahmad et al., 2018). For example, China’s extensive economic development combined with the rapid growth of energy consumption has also led to many greenhouse gas emissions (Riti et al., 2017).

Fortunately, a large number of studies have found evidence that renewable energy reduces pollution shocks. Chen et al. (2019) found that the global level of carbon dioxide emissions has increased due to the increase in the energy demand in recent decades. The primary approach to reduce CO₂ emissions

is to develop renewable energy. Their study showed that nonrenewable energy and GDP growth increased CO₂ emissions, while renewable energy and foreign trade harmed CO₂ emissions. A study on carbon emissions in Nigeria showed a significant negative impact of renewable energy on carbon consumption (Cosmas et al., 2019). Zhang and Zhao (2019) believed that the investment in R&D and renewable energy plays a vital role in reducing CO₂ emissions in China’s geographically advantageous areas. Noorpoor and Kudahi (2015) found that population size, per capita GDP, power intensity, and electricity consumption positively impact CO₂ emissions, while hydropower, nuclear power, and other renewable energy have a negative impact. Xu et al. (2019) showed that China’s per capita GDP and oil consumption are positively correlated with CO₂ emissions, while natural gas consumption hurts emissions. A considerable part of the research also exhibited that renewable energy consumption increases energy self-sufficiency, stimulates sustainable economic growth, and reduces CO₂ emissions (Noorpoor and Kudahi, 2015; Gill et al., 2018; Lin and Raza., 2019). Some studies suggested that there is not much relationship between nuclear energy and carbon emissions (Jaforullah and King, 2015; Cai et al., 2018).

Relevant studies made outstanding contributions on the relationships of energy use, CO₂ emissions, and economic growth. To our best knowledge, these studies paid more attention to the effects of LEE among different countries (Polemis and Dagoumas, 2013; Alper and Oguz, 2016; Ozturk, 2010) or within a country (Lee and Chang, 2005; Ho and Siu, 2007; Ang, 2008; Karanfil, 2008; Zhang and Cheng, 2009), which provided solid theoretical support for the research of this article. However, few of them concern the LEE policy, especially electricity in a disadvantaged region; few focused on the possible mechanism of clean electricity boosting economic growth and heterogeneous effects of clean electricity on different areas in a country. These issues all inspired this article.

RESEARCH DESIGN

Empirical Strategy

This article employs two-way fixed-effect model, SYS-GMM (System GMM method, Arellano and Bover, 1995), and panel quantile regression (Koenker, 2004; Harding and Lamarche, 2009) to survey the impacts of LEE on CO₂ emissions and economic growth.

1) Two-way fixed effect model

$$y_{it} = x_{it}'\beta + z_i'\delta + u_i + \varepsilon_{it}. \quad (1)$$

In Eq. 1, y_{it} denotes economic growth or CO₂ emissions, x_{it} denotes the key variables and time-variant variables, β denotes the corresponding coefficient, z_i denotes time-invariant variables, and δ denotes the corresponding coefficient. The error term had been divided into two parts: u_i denotes the time-invariant part, while ε_{it} represents the time-variant part.

For panel data, we should choose the random effect model (RE) or the fixed effect model (FE) according to the rule of Eq. 2. According to Hausman's method, if the difference between $\hat{\beta}_{RE}$ and $\hat{\beta}_{FE}$ is too large, we should choose $\hat{\beta}_{FE}$ as it will be relatively correct; otherwise, we should choose $\hat{\beta}_{RE}$ as it will be fully efficient. If the statistics is larger than the critical value, we should choose the FE model (Wooldridge, 2016),

$$\hat{\beta} = \begin{cases} \hat{\beta}_{RE} & \text{Corr}(u_i, z_i) = 0 \& \text{Corr}(u_i, x_{it}) = 0, \\ \hat{\beta}_{FE} & \text{Others.} \end{cases} \quad (2)$$

The corresponding hypothesis test and the corresponding statistics are shown in Eq. 3,

$$H_0: \text{Corr}(u_i, z_i) = 0 \& \text{Corr}(u_i, x_{it}) = 0$$

$$\text{Hausman} = (\hat{\beta}_{RE} - \hat{\beta}_{FE})' [\text{Var}(\hat{\beta}_{RE}) - \text{Var}(\hat{\beta}_{FE})] (\hat{\beta}_{RE} - \hat{\beta}_{FE})^{-p} \rightarrow \chi^2(K) \quad (3)$$

2) SYS-GMM

To avoid estimate bias by potential endogeneity, we can add the lag term of y_{it} and x_{it} , which are the instrumental variables for endogenous variables (LEE), in Eq. 1. Then, Eq. 1 will be transformed into Eq. 4.

$$y_{it} = \alpha + \rho_1 y_{i,t-1} + \rho_2 y_{i,t-2} \dots + \rho_p y_{i,t-p} + x_{it}' \beta + z_i' \delta + u_i + \varepsilon_{it}. \quad (4)$$

Then, based on Eq. 4, we can get the efficient estimator $\hat{\beta}_{\text{SYS-GMM}}$ by employing the GMM (generalized method of moments) method.

3) Panel quantile regression

To capture the provincial effect of LEE, we use the panel quantile regression model extended by Koenker (2004) and Harding and Lamarche (2009),

$$Q_{y_{it}}(\tau | x_{it}) = \alpha_i + x_{it}^T \beta(\tau) + e_{it}. \quad (5)$$

In Eq. 5, α_i is the individual fixed effect item that does not change with time, τ is the quantile, x_{it} is the independent variable, e_{it} is the individual random disturbance term, and $Q_{y_{it}}$ is the subsample dependent variable vector of the corresponding quantile τ .

Data

This article analyzed the effects of LEE on economic growth and CO₂ emissions in China. Some variables can be found in CBS (China Bureau of Statistics, <http://www.stats.gov.cn/tjsj/ndsj/>), which is the official organization responsible for the collection and publication of China's demographic, political, and economic data. CBS's official organization can offer variables such as fixed asset investment, employment, and per capita GDP. Other variables can be found in *China's environmental statistical yearbook* and *China energy statistical yearbook*, which could be easily found via the following link: <https://www.epsnet.com.cn/index.html#/Home>. From the two yearbooks, other variables, including CO₂ emissions, the production and consumption of clean electricity, the amount of

energy available for consumption in the region, the amount of electricity loss, and the total production and consumption of electricity, can be easily found out. Eventually, we obtain relatively complete data of 30 provinces in China from 2000 to 2017.

Variables

The proportion of LEE in total electricity consumption is used to capture the effects of clean electricity, which can overcome the trend of time and reflect the development and change of clean power more truly. To obtain a more efficient estimator of LEE on economic growth and CO₂ emission, we controlled the relevant variables, such as total fixed assets investment, the number of people in work, and total electricity consumption.

To avoid time trends on the regression results, we perform panel unit root tests (see table 2) and panel co-integration tests (see table 3) for all key variables. Both LLC and IPS methods show no panel unit root, which indicates that the main variables are stable and there is no strong time trend (see table 2). The Kao, Pedroni, and Westerlund test show that LEE, CO₂ emissions, and economic growth have a long-term relationship (see table 3). Next, we will use the panel data and the corresponding estimation methods to capture LEE's impact on economic growth and CO₂ emissions in detail. The description of variables is given in Table 1, the results of the panel unit-root test are shown in Table 2, and the panel cointegration test results are outlined in Table 3.

EMPIRICAL RESULTS AND ANALYSIS

Effects of LEE on Economic Growth

In Table 4, from model 1 to model 4, we can get the positive effect of LEE on economic growth consistently. Hausman statistics in Table 4 is 54.76, which is much larger than the critical value at the 5% significance level. Moreover, the corresponding p value is equal to 0.000, which shows strong support for FE. So, the results of FE are relatively correct. That is to say, keeping other variables fixed, when LEE increases by 1%, the GDP per capita will increase by 0.16%, and the parameter is significant.

However, a contrary effect of economic growth on LEE may exist. We cannot control the key variables, such as innovation, risk, and political reform, which may be the source of endogeneity. So, we restart to estimate the effects of LEE on economic growth by employing SYS-GMM. The results also support our conjecture. To better understand why LEE promotes economic growth, we choose some relevant variables, which are close to the economic function of LEE, from 2000 to 2015 to investigate the potential impact path. The related variables are listed in detail in Table 5. It should be emphasized that the data we found are hard to make a balanced panel. Nevertheless, the estimated results can also give us basic information on how LEE influences economic growth. After controlling the control variables, time effect, province effect, and their interaction, we get basic estimated results of LEE on relevant variables in Table 6. According to model 1 and model 2, LEE development could reduce transfer in the volume of electricity for some provinces in China. So, for some provinces whose economic source is power transmission, the inter provincial export of power

TABLE 1 | Description and definition of variables³.

Variables	Definition	Mean	Std. Dev
LEE	Proportion of clean electricity in total electricity consumption	0.228	0.229
Economic growth	ln (GDP per capita: Yuan)	10.022	0.842
CO ₂ emissions	ln (total carbon dioxide emissions: 0.1 billion tons)	15.443	0.774
Invest	ln (total fixed assets investment: 0.1 billion yuan)	8.381	1.275
Use	ln (total electricity consumption: 0.1 billion kwh)	7.839	0.674
Worker	ln (employment: Ten thousand people)	7.554	0.819
Observations		540	
Province		30	

TABLE 2 | Panel unit-root test.

Method	Levin-lin-chu (LLC)		Im-pesaran-shin (IPS)	
	Statistic	p-value	Statistic	p-value
LEE	-8.399	0.000	3.351	0.000
CO ₂ emissions	-8.128	0.001	-3.086	0.001
Economic growth	-2.862	0.002	1.885	0.970

TABLE 3 | Panel cointegration test.

Kao		Pedroni		Westerlund	
Statistic	p-value	Statistic	p-value	Statistic	p-value
-1.609	0.054	2.177	0.015	-3.131	0.001

will be obviously blocked. The results show that trade may be the short-term path for the effect of LEE on the economy, and it is hard to be the long-term one. To some extent, LEE can get rid of resource constraints for reducing local dependence on foreign electricity. In China, however, the diversity of geography and climate results in the congenital difference of clean resources. Although it is reasonable to develop local LEE, it is more important to give full play to the inherent advantages of resources, promote clean trade among regions, and achieve long-term stable growth (Table 6).

In terms of total LEE production, the quantity of electricity available for local consumption and the quantity of electric energy loss can also vividly demonstrate our ideas. The development of LEE promotes total LEE production and the quantity of electricity available for local consumption, which can partly support electricity's inner need. However, we should focus on the unobvious effects of LEE on the quantity of electric energy loss, which denotes the possible problems if a province only develops inner LEE without using the comparative advantages of other provinces rich in electric energy.

³Clean electricity here mainly includes nuclear energy, wind energy, and solar energy.

Effects of LEE on CO₂ Emissions

In Table 7, although different methods were used to estimate the effects of LEE on CO₂ emissions, we consistently obtained the same results. The Hausman test implied that we should choose model 4 as the most effective model. That is to say, *ceteris paribus*, if LEE increases by 1%, CO₂ emissions will approximately decrease by 0.848%. For lack of other control variables or ignorance effects of CO₂ emissions on LEE, the estimated coefficient of LEE on CO₂ emissions will be biased compared with true one (which means endogeneity probably exists in this study). Considering the potential endogeneity, we used SYS-GMM to capture the effect of LEE on CO₂ emissions. The corresponding coefficient is -0.782, which is highly consistent with model 1 to model 4. Thus, an adverse effect of LEE on CO₂ emissions may exist.

It is not hard to understand the negative effects of electric energy on CO₂ emissions. Its features, such as renewability, environmentally friendliness, circularity, and cost-effectiveness, reduce CO₂ emissions.

- 1) **Renewability:** Wind power, hydropower, and solar power are renewable energies. As long as they are reasonably used, these energy sources can continuously generate electricity and do not impact the environment.
- 2) **Environmental protection:** Promoting LEE can greatly reduce CO₂ emissions. For example, construction of large- and medium-sized biogas projects in large- and medium-sized livestock farms produces a large amount of rural energy and solves the pollution of livestock manure.
- 3) **Circularity:** Developing LEE will open up new resources for China's economic growth. For example, an animal husbandry farm with an annual output of 100,000 pigs can produce 58,400 tons of feces. When properly processed, these feces—which are currently not only wasted but also disposed of in a manner causing pollution—can become a valuable resource. If these feces can be used for power, it could produce 5.5 million kilowatts per hour, and these energy sources can be applied to production again and again, with endless benefits.
- 4) **Cost-effectiveness:** The development of LEE can protect the environment and serve as the chain of the circular economy industry. It can solve the issues related to wastewater, waste residue, and waste gas in the production process of upstream products and use these wastes as the main raw materials of

TABLE 4 | Effects of LEE on economic growth.

Variables	(1)	(2)	(3)	(4)	(5)
	RE	FE	RE	FE	SYS-GMM
LEE	0.116 (0.102)	0.222** (0.106)	0.103 (0.0677)	0.160** (0.0685)	0.436* (0.248)
Control variables	NO	NO	YES	YES	YES
Time effect	NO	YES	NO	YES	YES
Province effect	NO	YES	NO	YES	YES
Time × province effect	NO	YES	NO	YES	YES
Constant	8.872*** (0.0844)	8.848*** (0.0335)	5.211*** (0.186)	5.280*** (0.175)	-0.045 (15.97)
Hausman				54.76***	
AR (2)					0.772
Sargan					0.872
Observations	540	540	540	540	510
R-squared	0.971	0.971	0.988	0.988	---
Province	30	30	30	30	30

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, the estimated coefficient is displayed in the table, the numbers in the parentheses are the corresponding standard errors. Control variables, time effect, province effect, and their interaction are also controlled in **Table 6**, **Table 8**, **Table 9**, **Table 10**, and **Table 11**.

TABLE 5 | Description and definition of relevant variables.

Variable	Definition	N	Mean	Std. deviation
Loss	ln (quantity of electricity loss)	454	3.906	1.078
Out_trans	ln (transfer out volume of the province)	451	-3.898	2.171
In_trans	ln (transfer in volume of the province)	468	3.842	2.265
TCE	ln (total clean electricity production)	519	4.493	1.942
Consumption	ln (quantity electricity available for local consumption)	536	3.457	4.189

Notes: The rule of choosing relevant variables (RV): generate $RV = \ln(RV)$, if $RV > 0$ and generate $RV = -\ln(-RV)$, otherwise. The unit of all the original variables is 0.1 billion kWh.

TABLE 6 | Effects of LEE on relevant variables.

Variables	(1)	(2)	(3)	(4)	(5)
	Trade		Supply		Efficiency
	Out_trans	In_trans	TCE	Consumption	Loss
LEE	-0.569 (0.853)	-2.192* (1.117)	2.814*** (0.603)	6.016*** (1.456)	-0.0686 (0.722)
Constant	-15.64 (90.76)	-340.4*** (113.8)	54.60 (60.93)	695.2*** (147.0)	50.13 (74.44)
Observations	451	468	519	536	454
R-squared	0.666	0.537	0.795	0.554	0.462
Province	29	30	30	30	29

downstream products. It can save a lot of raw materials and has high economic value for production.

Based on the above analysis, the features of LEE and their influence on CO₂ emissions are outlined in **Figure 1**.

Discussions on Regional Heterogeneity

From **Table 4,7**, we find the positive effect of LEE on economic growth, and enough supply for the local province may be the potential path for its effects. Furthermore, we also show the contradiction of the province trade of the prosperous internal supply and the declining external supply of electricity, which will harm the balance of the economy. In this part, panel quantile

regression and regression by areas are employed to test the ideas again.

The results of **Table 8** demonstrate that the positive influence of LEE on economic growth would increase with the increase in economic growth, especially in Q75 and Q90, which implies that LEE will vigorously promote the economic growth of high-development areas compared to the low-development ones. The corresponding reason is far more likely that the regions that are economically disadvantaged do not have the resources to invest in LEE, while the regions that are economically advantaged do have the resources.

As for the results of **Table 9**, all the models cannot get a significant effect of LEE on CO₂ emissions. However, the results

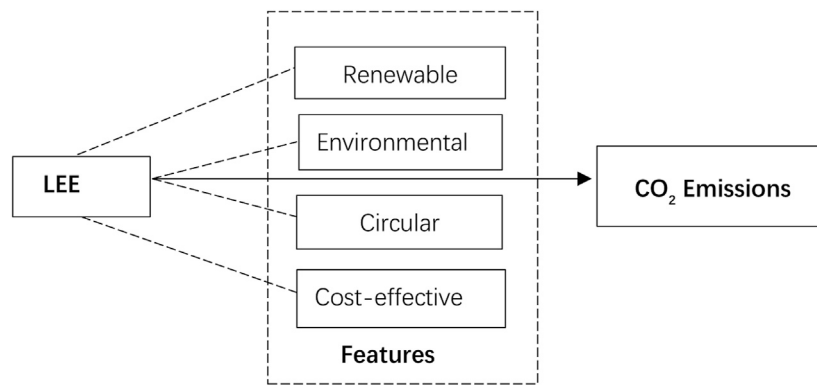


FIGURE 1 | Features of LEE and its influences on CO₂ emissions.

TABLE 7 | Effects of LEE on CO₂ emissions.

	(1)	(2)	(3)	(4)	(5)
	RE	FE	RE	FE	SYS-GMM
LEE	-0.974*** (0.241)	-0.678** (0.325)	-0.738*** (0.202)	-0.848*** (0.286)	-0.782** (0.320)
Control variables	NO	NO	YES	YES	YES
Time effect	NO	YES	NO	YES	YES
Province effect	NO	YES	NO	YES	YES
Time × province effect	NO	YES	NO	YES	YES
Constant	14.83*** (0.118)	14.76*** (0.103)	7.881*** (0.839)	3.822*** (1.227)	10.33*** (1.653)
Hausman					22.51***
AR (2)					0.331
Sargan					1.00
Observations	540	540	540	540	510
R-squared	0.596	0.596	0.686	0.693	---
Province	30	30	30	30	30

TABLE 8 | Panel quantile regression of LEE on economic growth.

Economic growth	(1)	(2)	(3)	(4)	(5)
	Q10	Q25	Q50	Q75	Q90
LEE	0.0357 (0.163)	0.0772 (0.129)	0.150 (0.0921)	0.244** (0.124)	0.300* (0.170)
Observations	540	540	540	540	540

TABLE 9 | Panel quantile regression of LEE on CO₂ emissions.

	(1)	(2)	(3)	(4)	(5)
	Q10	Q25	Q50	Q75	Q90
LEE	-0.543 (25.81)	-0.702 (4.486)	-0.839 (14.57)	-0.946 (29.01)	-1.036 (41.17)
Observations	540	540	540	540	540

show that the province could reduce its CO₂ emissions more if its previous CO₂ emission is too significant. Moreover, it is not fair in terms of development equity because the high-development

TABLE 10 | Regression of LEE on CO₂ emissions and economic growth by areas.

	(1)	(2)	(3)	(4)	(5)	(6)
	Economic growth			CO ₂ emissions		
	West	Central	East	West	Central	East
LEE	0.232*** (0.0813)	-0.0855 (0.128)	0.227*** (0.0707)	0.245 (0.562)	-0.223 (0.416)	-0.812*** (0.299)
Constant	-1.317 (4.624)	20.37*** (3.938)	-7.286 (4.500)	-58.78* (30.83)	16.73 (14.70)	54.43*** (18.63)
Observations	198	108	234	198	108	234
R-squared	0.997	0.997	0.997	0.834	0.947	0.882
Province	11	6	13	11	6	13

areas based on significant CO₂ emissions can enjoy more benefits from CO₂ emission reduction and economic growth than the low-development ones.

The results of regression by areas also support our idea further (see **Table 10**). Model 1 and model 4 show that LEE can promote the economic growth of western areas but hamper the reduction in CO₂ emission. However, model 3 and model 6 indicate that

TABLE 11 | Annual effects of LEE on CO₂ emissions and economic growth.

Variables	(1)		(2)	
	Economic growth		CO ₂ emissions	
	β_1	<i>p</i> -value1	β_2	<i>p</i> -value2
Control group: 2000×CE				
2001×LEE	-0.0251	(0.642)	-0.0360	(0.893)
2002×LEE	-0.0279	(0.627)	-0.271	(0.339)
2003×LEE	-0.0713	(0.263)	-0.710**	(0.024)
2004×LEE	-0.0692	(0.309)	-0.844**	(0.012)
2005×LEE	-0.0921	(0.217)	-0.817**	(0.026)
2006×LEE	-0.0727	(0.376)	-0.733*	(0.071)
2007×LEE	-0.0364	(0.689)	-0.717	(0.111)
2008×LEE	-0.0562	(0.559)	-0.766	(0.107)
2009×LEE	-0.0658	(0.535)	-0.804	(0.125)
2010×LEE	-0.0216	(0.852)	-0.925	(0.104)
2011×LEE	0.0069	(0.956)	-0.903	(0.143)
2012×LEE	0.0330	(0.799)	-0.793	(0.216)
2013×LEE	0.0690	(0.626)	-0.950	(0.174)
2014×LEE	0.0716	(0.624)	-0.947	(0.189)
2015×LEE	0.0974	(0.519)	-0.884	(0.236)
2016×LEE	0.121	(0.452)	-0.886	(0.264)
2017×LEE	0.0856	(0.613)	-0.999	(0.233)
Constant	-20.47***	(0.001)	6.147	(0.844)
Observations	540		540	
R-squared	0.996		0.859	
Province	30		30	

LEE can effectively make economic growth and reduce CO₂ emissions together in eastern areas. As for central regions, the impacts of LEE are not significant. The results demonstrate that an LEE policy may benefit the eastern and western regions but makes no difference to central regions. Western areas have rich natural resources for producing low-emission electricity, and eastern areas can take full technological advantage of LEE. Although LEE can promote the economic growth of western and eastern areas, CO₂ emissions of constructing LEE facilities could be detained in western areas. Due to the lack of comparative advantages of natural resources and technological innovations, the LEE has no significant impact on the central areas.

Discussions on Annual Heterogeneity

Based on Eq. 1, we add the interaction of LEE and time variable⁴, where ϕ denotes the coefficient of the corresponding year,

$$y_{it} = \sum_{year=2001}^{2017} \phi_{year} year \times CE + x'_{it} \beta + z'_i \delta + u_i + \varepsilon_{it}. \quad (6)$$

By this way, we can capture the annual effects of LEE on economic growth and CO₂ emissions (results estimated are shown in Table 11). β_1 and β_2 denote the impact of LEE on economic growth and CO₂ emissions, while *p*-value1 and *p*-value2 are their significance separately (see Table 11).

Figure 2 captures the annual heterogeneity LEE's influence on economic growth and CO₂ emissions in Table 11. As shown in

Figure 2A, β_1 is smaller than zero before 2011 but larger than zero after 2011. Although LEE's annual effects on economic growth are not significant, the corresponding coefficient implies the potential relationships between LEE and economic growth. The previous technology development and infrastructure construction of LEE need high costs. Only when these costs reach a particular scale can LEE promote the economy. After 2011, the positive effect of LEE on economic growth arises, and China maybe jumps into the range of growth benefits. As shown in Figure 2B, β_2 becomes smaller and smaller with time and *p*-value2 is also small, which implies the increasing effects of LEE on CO₂ emissions.

DISCUSSIONS AND CONCLUSIONS

Conclusions

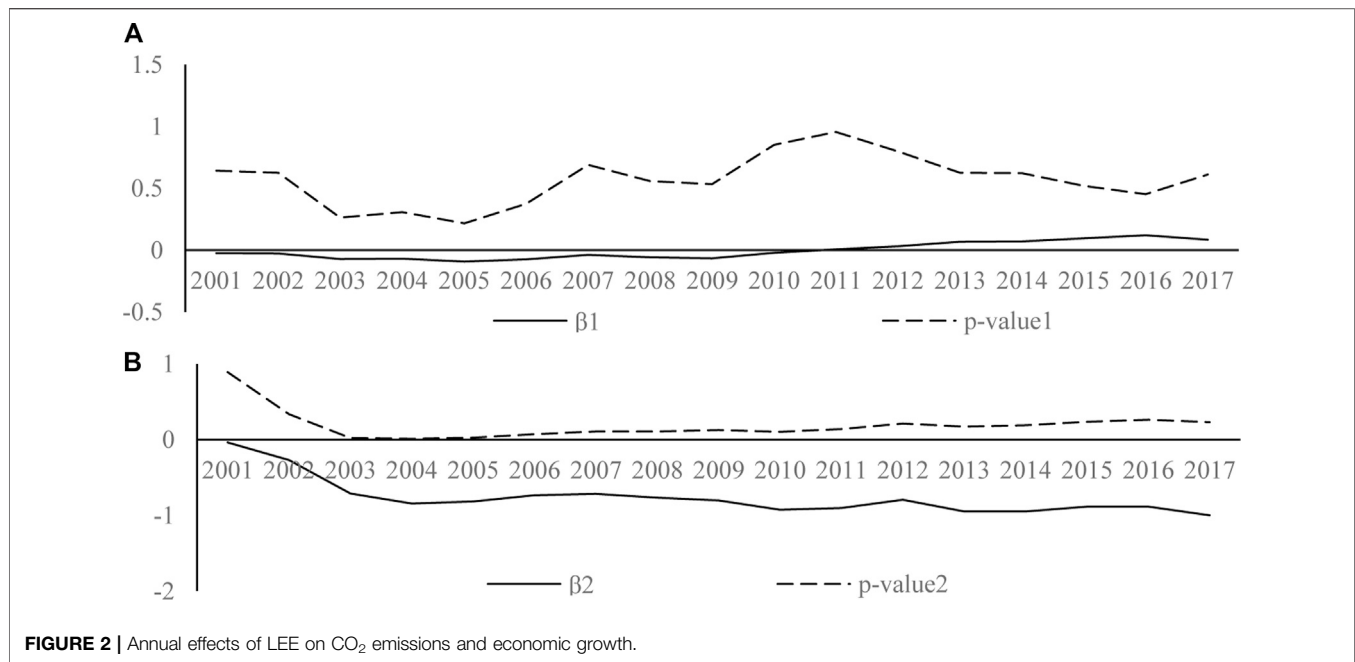
Using the provincial panel data from 2000 to 2017 in China, we investigate the effects of LEE on economic growth and CO₂ emissions. The results show that LEE development can achieve the reduction in CO₂ emissions and economic growth simultaneously. However, we should not ignore the reasons for LEE to regional heterogeneity. For economic growth, LEE can add the supply of LEE and electricity available to local consumption without any help to trade and efficiency. Therefore, the adverse effects of LEE on economic growth may be short-term and regional unbalance.

Then, according to the regional and annual heterogeneity, this work shows further evidence for these ideas. The results of regional heterogeneity exhibited that the effects of LEE on economic growth and CO₂ emissions in eastern areas are better than those in western and central areas. Thus, LEE may widen the income gap between different areas. The results of annual heterogeneity imply that the effects of LEE on economic growth arise nowadays. However, the annual effects of LEE may be a little and not significant at the 5% significance level, which denotes the effects of LEE on economic growth, maybe short term.

Policy Implication

It is very unwise to have an economy dependent on finite resources for the trend in fossil fuels is more expensive extraction. The phenomenal growth of light tight oil produced from fracking has produced little profit (Craig, 2020). Second, in many regions, solar energy is now cheaper than coal energy (IEA, 2020). If the global epidemic is under control, the world's energy demand will recover by 2025 (IEA, 2020), but fossil fuel supply may struggle to keep up in the short term. Under-investment in oil exploration, for example, is a predictor of future oil price shocks (Hacquard et al., 2019). So, China should diversify its energy mix before it is obliged to because of decreasing availability of fossil fuels. Our research may provide valuable shreds of evidence for LEE policy. On the one hand, carrying out an LEE policy can reduce CO₂ emissions and promote economic growth. However, on the other hand, regional heterogeneity implies that the policymakers should focus on the details of the policy being carried out. The policy implications are outlined as follows.

⁴For avoiding dummy variable trap, 2,000 is not considered.



First, this article demonstrates that LEE can make CO₂ emission reduction and economic growth compatible, but energy efficiency needs to be further enhanced. So, we should pay much attention to the LEE policy in the future. On the one hand, the government needs to strengthen financial investment in LEE and improve energy infrastructure construction; on the other hand, the government should pay attention to the improvement of LEE production technology, strive to improve energy production efficiency, and strive to achieve energy decarbonization as soon as possible.

Second, an LEE policy should be carried out in regions with comparative advantage of resources. Technological advantages of developed areas can be combined with the resource advantages of less developed areas. Even if the developed regions can achieve LEE self-sufficiency, they should also support the less developed regions as far as possible and help them transform their resource advantages into technological and economic advantages.

Third, early construction of LEE needs a lot of human, material, and financial resources and may have a certain degree of negative impact on the environment. Therefore, the development of LEE needs to pay attention to two crucial issues. On the one hand, policymakers should consider whether the current economic situation can support sustainable LEE construction. On the other hand, they should pay more attention to environmental protection in the construction process.

Finally, in developing LEE, those areas that have neither comparative technology advantage nor resource comparative advantage may not enjoy the blessing of LEE. For these areas, the government needs to tap their regional advantages, increase financial strength, and avoid an excessive regional development gap.

DATA AVAILABILITY STATEMENT

Data used in this study are available (<https://www.epsnet.com.cn/index.html#/Home>), all the code and data can be downloaded by private link (<https://pan.baidu.com/s/17VSQtHQbXkDpc9NsSR2MTQ>, Password of accessing is 6rid). Further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

ZZ wrote and revised this paper, Y-HC provided suggestions for the revision and framework of this paper, and C-MW gave some ideas of this paper.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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