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How green growth affects carbon emissions in China: the role of green finance

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ABSTRACT
Accelerating the green transition of the economy is an effective way to conserve energy and reduce emissions, and its impact on the greenhouse effect deserves in-depth discussion. Based on this, we examine the potential effect of China's green growth on carbon dioxide (CO_2) emissions by applying provincial panel data from 2004 to 2018. The regional heterogeneity and how does green finance affect the green growth-CO_2 nexus are also checked. The primary findings imply that: (i) China's green growth achieves preliminary results, and its impact on CO_2 emissions is significantly negative. Also, green finance can facilitate carbon emission reduction; (ii) significant regional heterogeneity exists within various regions. Only in the central and western regions can green growth effectively reduce CO_2 emissions, and in the eastern and central regions, green finance is conducive to promoting carbon reduction; and (iii) the mediating role of green finance is significant. In other words, China's green growth not only mitigates the greenhouse effect directly, but also affects CO_2 emissions indirectly by accelerating the development of green finance.

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1. Introduction

Since the reform and opening up proposed in 1978, China's economy has achieved remarkable progress, and its economic aggregate has been rising rapidly (Dong et al., 2018). As Jiang et al. (2020a) and Ren et al. (2022) stress, huge economic aggregate and rapid economic development are usually driven by a large amount of fossil energy consumption, and the excessive consumption of coal and oil often emits massive carbon dioxide (CO_2) emissions. However, as International Energy Agency (IEA) stresses, the outbreak of corona virus disease 2019 (COVID-19) in 2019 severely

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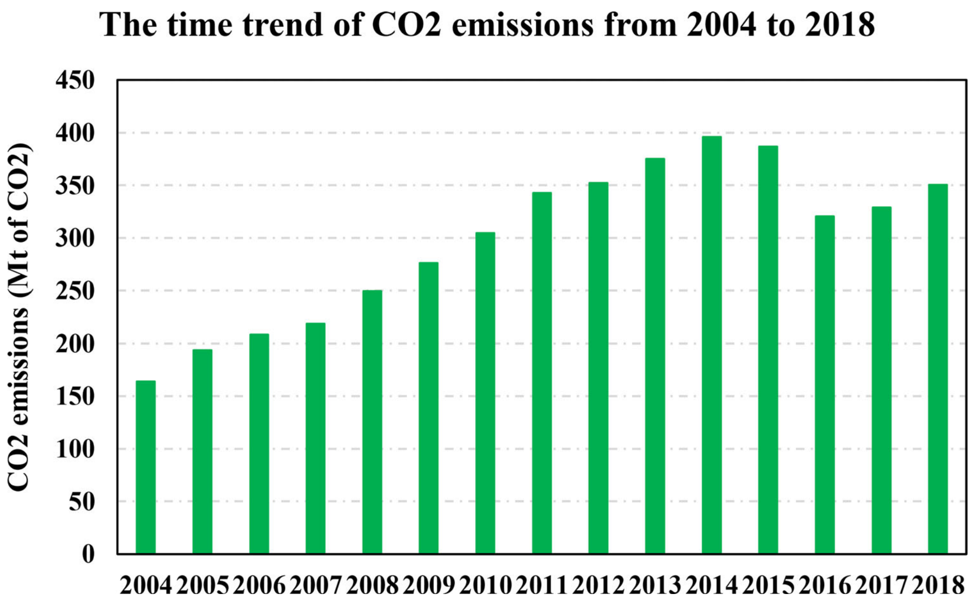

Figure 1. Time trend chart of the average values of CO_2 emissions from 2004 to 2018.
Source: Self-calculated according to the data of CEADs (2019).

restricted international trade and production activities of enterprises, significantly reversed the trend of surging CO_2 emissions (Tu & Rasoulinezhad, 2021). Following the statistics of former British Petroleum (BP, 2021), China's primary CO_2 emissions in 1978 were 1,418.5 million tonnes of CO_2 (Mt of CO_2), while in 2020, the amount of CO_2 emissions was 9,893.5 Mt of CO_2, approximately seven times the CO_2 emissions produced 42 years earlier. In addition, we draw the time trend chart of average values of CO_2 emissions across various provinces by following the data of China Emission Accounts and Datasets (CEADs, 2019) (see Figure 1). Obviously, China's CO_2 emissions from 2004 to 2018 show an inverted U-shaped nexus and peak in 2014, which indicates the effectiveness of continuous carbon emission reduction. Furthermore, Figure 2 presents the spatial distribution of per capita CO_2 in 2018, which exhibits that CO_2 emissions in the eastern and northern provinces are significantly higher than those in the central and western provinces, and a gradient weakening trend exists from east to west. Based on this, China aims to achieve its carbon neutrality goal by reducing carbon emissions at the national level, which emphasizes China's determination to mitigate the greenhouse effect and alleviate the deterioration of the ecological environment (Jiang et al., 2022).

Green growth is proposed under the framework of sustainable economic growth, which aims to emphasize the coordinated socio-economic development, improve social welfare, increase employment, and effectively solve the problems of resource allocation and environmental degradation by changing consumption and production patterns (Hao et al., 2021). Since green growth was strongly advocated, more and more scholars began to define green growth. For instance, Hallegatte et al. (2012) stress that green growth refers to the process of realizing a resilient, clean, and energy-saving economic system. Hickel and Kallis (2020) define green growth as absolute decoupling of economic growth and environmental degradation. The

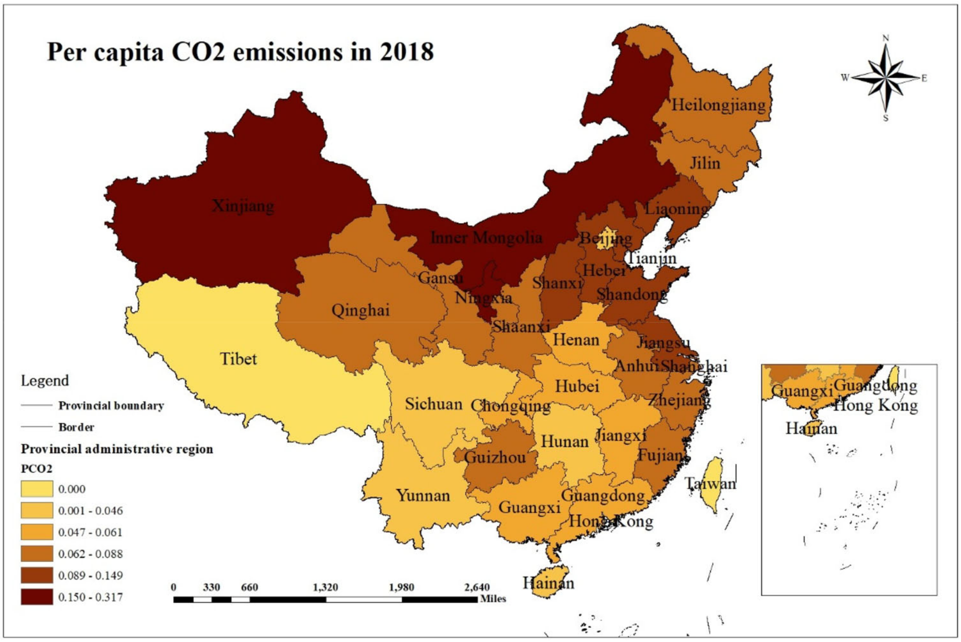

Figure 2. Spatial distribution of per capita CO_2 emissions in 2018.
Source: Self-calculated according to the data of CEADs (2019).

Organization for Economic Co-operation and Development (OECD) has put forward an authoritative definition: green growth refers to the promotion of economic growth while ensuring that natural assets can continue to provide various resources and environmental services for humans' well-being. With the vigorous advocacy of the concept of green growth, all walks of life accelerate transformation and upgrading under the guidance of national policies and directions, decrease dependence on traditional high-polluting energy, and actively carry out the research and development (R&D) of low-carbon technologies. Among them, the financial industry provides sufficient capital support for green transition and is a strong guarantee for enterprises to optimize and upgrade (Taghizadeh-Hesary & Yoshino, 2019). With the continuous advancement of green finance, the support of financial institutions for environmental protection enterprises can effectively guide the transfer of resources from high-carbon industries to low-carbon industries, which can help reduce CO_2 emissions.

Considering the above background, whether the current development of green growth in China can help alleviate the greenhouse effect deserves in-depth exploring; this is particularly useful for effectively identifying and assessing China's green growth process. Furthermore, as Figure 2 shows, due to the differences in economic driving forces, the distribution of CO_2 emissions in each province is obviously heterogeneous, testing whether regional heterogeneity exists in the impact of China's green growth on CO_2 emissions is imperative. In addition, with the rapid growth of green finance, exploring the role of green finance in adjusting the green growth-CO_2 nexus is crucial for seeking for the specific influence channels of green growth in affecting CO_2 emissions. Thus, this study applies a provincial sample dataset covering the period 2004–2018 to explore whether green growth can help facilitate the reduction of carbon emissions in China, and further discusses the regional heterogeneous impact of China's green growth on CO_2 emissions by dividing the full sample into three regions: the eastern, central, and western regions. In addition, whether green finance will stimulate the effect of green growth on CO_2 emissions is investigated.

Consequently, the study contributes to the current literature on green growth and CO_2 emissions in the following three aspects: (1) It creatively assesses the reduction of carbon emissions in the process of China's green growth by constructing a green growth composite index. This not only helps identify the specific actuality of China's green growth, but also effectively evaluates the potential effect of China's green growth on carbon neutrality; (2) due to the significant difference of carbon emissions in various provinces, the regional heterogeneous impact of green growth on CO_2 emissions across different regions is discussed; this exploration can effectively help local governments to develop specific and practical strategies for accelerating carbon emission reduction and achieving green growth according to local conditions; and (3) the mediation role of green finance in affecting the green growth-CO_2 nexus is empirically explored in the study. This discussion is of great value for policymakers and governments to leverage the role of financial institutions in capital regulation of green growth and CO_2 emissions and adjust the effect of green growth on greenhouse effect from accelerating green growth of financial industry.

The remaining framework of this study is structured as follows. The related literature on green growth and CO_2 emissions is provided in the next section. Section 3 analyzes the theoretical mechanism between green growth and CO_2 emissions. Section 4 constructs the model and presents the data sources, followed by the estimated results in Section 5. Section 6 further explores whether improved green finance can affect the role of green growth in reducing CO_2 emissions. Section 7 concludes our study and develops a series of policy implications.

2. Literature review

2.1. An overview of green growth

Whether countries with limited resources can find a way to develop their economy and at the same time mitigate environmental damage through green growth is a question that has occupied the minds of numerous scholars, environmentalists, and economists. To explore a sustainable low-carbon development model, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) first proposed the concept of green growth (ESCAP, 2005). This sustainable approach to development has aroused considerable interest among scholars globally, and discussions on green growth are growing. In addition, the OECD defines green growth as a development method in which economic growth is coordinated with the ecological environment to achieve sustainable economic development (OECD., 2011). This definition is also reached by Xu et al. (2020). Green growth is widely supported and recognized as a sustainable development model (Zhao et al., 2022b).

Scholars have advanced different views on the measurement of green growth. The growth rate of green total factor productivity (GTFP) obtained by the Malmquist-Luenberger (ML) index is often used to reflect green growth, and has been optimized by later scholars using data envelopment analysis (DEA) and directional distance function (DDF) (Zhu et al., 2022). Furthermore, Kim et al. (2014) develop indicators for assessing green growth using the OECD framework. In addition, the inequality-adjusted human development index (HDI), inclusive wealth index (IWI), and sustainability window analysis are used to measure green growth. In addition, Zhao et al. (2022b) creatively build an indicator system including three aspects (i.e., economic growth, people's livelihood, and environment) to gauge a composite index of green growth based on the improved entropy method. Obviously, there is no uniform measure of green growth, especially in China.

2.2. The green growth-CO_2 nexus

To meet the needs of economic development, human beings have consumed a large amount of fossil energy (e.g., coal and oil) and released massive CO_2 emissions into the atmosphere, leading to a series of adverse consequences, such as global warming and rising sea levels (Dong et al., 2017; Ozturk et al., 2021; Zhao et al., 2022a). The serious harm of the greenhouse effect has attracted global attention, and carbon emission reduction has become a worldwide problem. Countries have begun to seek development methods to achieve a win-win situation for economic growth, and carbon emission reduction through green growth is considered a feasible solution.

The research on green growth and carbon emissions can be traced back to the discussion of the causal relationship between economic growth and CO_2 emissions. In this context, some scholars confirm that rapid economic growth has a significant impact on CO_2 emissions (Acheampong, 2018; Chen et al., 2016; Mikayilov et al., 2018; Ozturk & Salah Uddin, 2012; Shahbaz et al., 2018; Wang et al., 2018); conversely, Gorus and Aydin (2019) and Salahuddin et al. (2016) support the finding that no causal relationship exists between economic growth and the greenhouse effect. Based on this, increasing numbers of scholars have begun to investigate the impact of green growth on the greenhouse effect. In this regard, Hao et al. (2021) used the Cross-Sectionally Augmented Auto-regressive Distributive lag (CS-ARDL) model and found that green growth can significantly reduce CO_2 emissions. In addition, by applying the quantile autoregressive distributed lag approach, Chien et al. (2021) suggest that green growth has a significant negative impact on the greenhouse effect. They believe green growth is an environment-friendly development mode with limited resources. This finding is basically consistent with the conclusion of Alper and Oguz (2016) and Guo et al. (2017): green growth is negatively associated with the greenhouse effect. The specific descriptions of these literatures related to growth-CO_2 nexus are presented in Table A1 of Appendix. However, notably, there is currently less relevant literature on China's green growth-CO_2 emissions nexus, which is crucial for China's carbon peak and carbon neutrality.

2.3. Literature gaps

Although some scholars have investigated the impact of green growth on CO_2 emissions, several research gaps still exist. First, although some indexes such as the ML, HDI, and IWI indexes are employed to measure green growth, and some scholars have effectively and comprehensively assessed green growth for the case of China (Zhao et al., 2022b), the effect of green growth on carbon emission reduction has not received much attention. Second, the spatial distribution of CO_2 emissions implies regional heterogeneity across various provinces; however, few studies have examined the differential impact of China's green growth on carbon emissions. Third, while vigorously advocating green growth, the green development of the financial industry has also received much attention from the academic community. However, whether green finance is an effective channel for China's green growth to mitigate the greenhouse effect has not been comprehensively discussed.

3. Theoretical mechanism

To the best of our knowledge, green growth mainly underscores the greening and intensification of the economy (Zhao et al., 2022b). Although the concept of green growth has different emphasizes from circular economy, low-carbon economy, and ecological economy, its core is the same, and it mainly advocates the concept of comprehensive coordination and sustainable development between economy, society, ecological environment, and natural resources. To accelerate the harmonious development of the economic growth and environment, on the one hand, local governments will successively issue relevant policies and regulations on carbon emission reduction and green innovation to create a policy environment for green growth (Xu et al., 2020). In addition, national agencies will allocate funds to local governments and environmental protection enterprises for the R&D of green technologies, creating a capital base for enterprises to carry out technological expansion and innovation (Dong et al., 2021). On the other hand, enterprises, especially energy and high-polluting enterprises, will actively respond to the goal of achieving carbon neutrality by phasing out outdated capacity and accelerating corporate transformation and technological innovation. These measures play a decisive role in alleviating the greenhouse effect.

In addition to the direct role of the government and enterprises mentioned above, financial institutions will gradually play their role of capital regulation under the policy advocacy of green growth, and increasingly become the effective driving force of energy transition and environmental improvement. More importantly, the financial sector regards environmental protection as a basic policy, considers potential environmental effects in the process of investment and financing, and actively provides financial services such as risk management, investment and financing, and project operation for projects related to clean energy, green buildings, and green transportation (Tran, 2021). Furthermore, green finance pays attention to the protection of ecological environment in financial operation activities, and alleviates the greenhouse effect by guiding the transfer of limited resources of economy and society from high-polluting areas to low-energy areas. Based on the above analysis, we propose the following hypotheses:

Hypothesis 1: Accelerating green growth can help reduce CO_2 emissions.

Hypothesis 2: Green growth can mitigate the greenhouse effect by facilitating the greening of financial institutions.

4. Empirical model and data sources

4.1. Empirical model

To empirically investigate the underlying impact of China's green growth on CO_2 emissions, we construct an econometric model with green growth and green finance as the core explanatory variables and CO_2 emissions as the explained variable by referring to the three effects (i.e., economy, technology, and structure) proposed by Copeland and Taylor (1994), which are represented by *Pgdp*, *EE*, and *ISU*, respectively. In addition, we also introduce the variables of trade openness and income inequality to reflect the impacts of trade flows and residents' income, which increases the accuracy of assessing the relationship between green growth and carbon emissions. The specific estimated model is presented in the following equation:

$$\begin{aligned} \ln CO_{2it} = \alpha_0 + \alpha_1 \ln GGI_{it} + \alpha_2 \ln GFI_{it} + \alpha_3 \ln Pgdp_{it} + \alpha_4 \ln EE_{it} + \alpha_5 \ln ISU_{it} \\ + \alpha_6 \ln Tra_{it} + \alpha_7 \ln Gap_{it} + \nu_i + \mu_t + \varepsilon_{it} \end{aligned} \quad (1)$$

where subscript i refers to China's 30 provinces within the sample data, and t means the sample period, 2004–2018. α_0 represents the constant term, and $\alpha_k(k = 1, 2, \ldots, 7)$ indicates the coefficients of the variables to be estimated. ln stands for the natural logarithm of each variable. CO_2 refers to the carbon emissions of each province, and *GGI* represents green growth. *GFI*, *Pgdp*, *EE*, *ISU*, *Tra*, and *Gap* indicate green finance, economic growth, energy efficiency, industrial structure upgrading, trade openness, and income inequality, respectively. ν_i refers to province-specific effect, μ_t denotes time-specific effect, and ε_{it} means error term.

Notably, China's green growth goal aims to facilitate the coexistence of rapid socio-economic development and a sound environment; thus, the estimated coefficient of green growth (i.e., α_1) may be negative. In addition, the coefficients of ln*GFI*, ln*Pgdp*, ln*EE*, ln*ISU*, and ln*Tra* are expected to be negative, and the coefficient of ln*Gap* (i.e., α_7) is expected to be positive.

4.2. Variables and data sources

Annual data covering the period 2004–2018 of China's 30 provinces are employed in this study to investigate whether China's green growth process can help accelerate the realization of the goal of mitigating greenhouse effect. It is worth noting that data from other years are not included in this study, as environment-related data in the China Environment Statistical Yearbook (CESY, 2019) were only updated to 2018. Other provinces are not considered due to missing data.

As the main research variables of our study, we first propose the specific steps of gauging green growth and green finance, as follows:

1. Green growth (denoted as *GGI*). To effectively and comprehensively assess green growth in China, we construct a composite index of green growth with three dimensions (i.e., economic growth, people's welfare, and ecological environment); the specific indicators and measurement method of the composite index can refer to the relevant research of Zhao et al. (2022b). In addition, we further measure the sub-indexes of green growth: the economic growth index (denoted as *GGI_1*), the people's welfare index (denoted as *GGI_2*), and the ecological environment index (denoted as *GGI_3*). The relevant data were collected from several publicly available yearbooks in China.
2. Green finance (denoted as *GFI*). Similar to green growth, there is currently no unified indicator for measuring green finance in China. Accordingly, referring to Jiang et al. (2020b) research, we construct a composite index of green growth that includes economy, finance, and the environment based on the improved entropy method. Given the length of the article, the specific measurement steps of this method can refer to the work of Zhao et al. (2022b). To be more specific, economy includes three indicators (i.e., per capita gross domestic product (GDP), per capita disposable income, and unemployment rate); finance consists of eight indicators (i.e., number of banks per area, number of bank staff per area, number of banks per capita, number of bank staff per capita, deposits, loans, the density of insurance, and the depth of insurance); and six indicators are included in environment (i.e., the rate of wastewater, the rate of sulfur dioxide, the rate of solid waste, the rate of energy consumption, the rate of nature reserves, and the rate of forests). The specific measures and properties of the indicators are reported in Table A2. The data on economy are from the China Statistical Yearbook (CSY, 2019), the environmental data were obtained from the CESY (2019), and the China Regional Financial Operation Report (CRFOR) provides the data on finance.

After calculating the composite index of green growth and green finance of each province, we plot the time trend chart of the annual average values of green growth and green finance from 2004-2018 (see Figure 3). Obviously, during the sample period, green growth generally shows a U-shaped trend, while green finance presents an inverted U-shaped characteristic. In addition, we present a table including the symbols, definitions, and data sources of variables in Table A3, and the descriptive statistics of all the used variables are presented in Table 1.

5. Empirical findings

5.1. Pre-benchmark analysis

Prior to the benchmark estimate, this study examines the multicollinearity between the explanatory variables (see the first column of Table 2). It is clear that the values of the variance inflation factor (VIF) of each explanatory variable and the mean VIF are all less than 10. This implies that there is no multicollinearity among the explanatory variables selected in this study. Table 2 also lists the correlation coefficients between variables. Obviously, the correlation coefficient between green growth (i.e.,

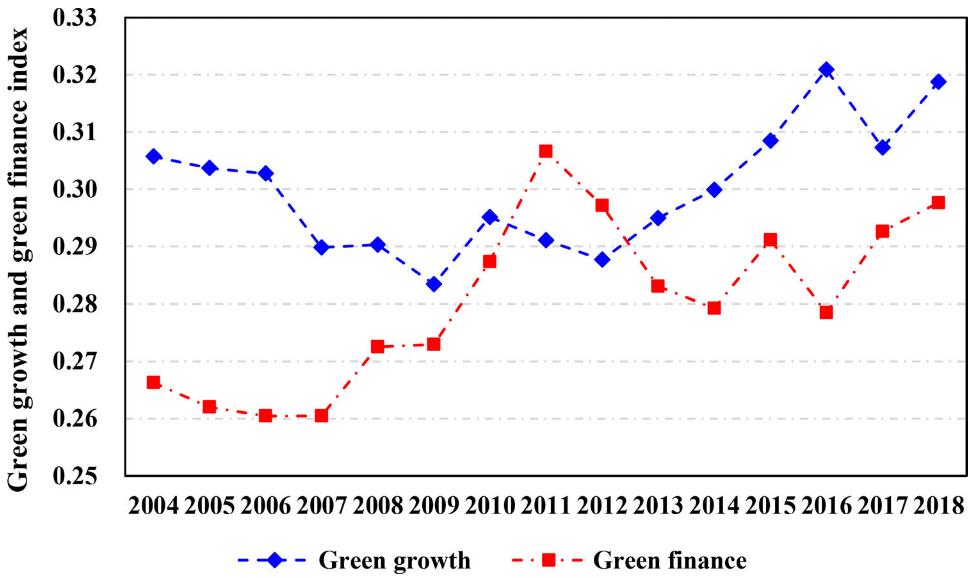

Figure 3. Time trend chart of the average values of green growth and green finance from 2004 to 2018, respectively.
Source: Self-calculated according to the data gauged in Section 4.2.

Table 1. Definitions and descriptive statistics of the selected variables.

Variable	Definitions	Obs.	Mean	Std. dev.	Minimum	Maximum
lnCO_2	CO_2 emissions	450	5.408042	0.8125148	1.757858	7.348459
ln*GGI*	Green growth	450	−1.241189	0.262392	−1.787667	−0.4596898
ln*GFI*	Green finance	450	−1.347638	0.367188	−2.031035	−0.1971542
ln*Pgdp*	Economic growth	450	10.35204	0.6851362	8.370316	11.8509
ln*EE*	Energy efficiency	450	0.0777888	0.5395829	−1.463981	1.428051
ln*ISU*	Industrial structure upgrading	450	−0.060077	0.3731148	−0.6990584	1.469621
ln*Tra*	Trade openness	450	−1.662734	0.97987	−4.085905	0.5679131
ln*Gap*	Income inequality	450	1.032355	0.1843939	0.6125599	1.560063

Note: Std. Dev. refers to standard deviation.
Source: Self-calculated.

Table 2. Test results for multicollinearity and correlation checks.

	VIF	lnCO_2	ln*GGI*	ln*GFI*	ln*EE*	ln*ISU*	ln*Pgdp*	ln*Tra*	ln*Gap*
lnCO_2	–	1.0000							
ln*GGI*	2.99	−0.1463*	1.0000						
		(0.0019)							
ln*GFI*	3.37	−0.1973*	0.7330*	1.0000					
		(0.0000)	(0.0000)						
ln*EE*	2.82	0.1370*	0.4369*	0.3981*	1.0000				
		(0.0036)	(0.0000)	(0.0000)					
ln*ISU*	1.87	−0.3259*	0.4958*	0.6043*	0.4090*	1.0000			
		(0.0000)	(0.0000)	(0.0000)	(0.0000)				
ln*Pgdp*	3.82	0.3220*	0.5196*	0.5548*	0.7279*	0.3732*	1.0000		
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)			
ln*Tra*	2.96	0.0105	0.6944*	0.6302*	0.4986*	0.3044*	0.4160*	1.0000	
		(0.8242)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)		
ln*Gap*	2.36	−0.2417*	−0.3601*	−0.4019*	−0.6058*	−0.2408*	−0.6999*	−0.4941*	1.0000
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
Mean VIF	2.88								

Note: * refers to $p < 0.1$, and the data in parentheses denote the *p*-value of the correlation test.
Source: Self-calculated.

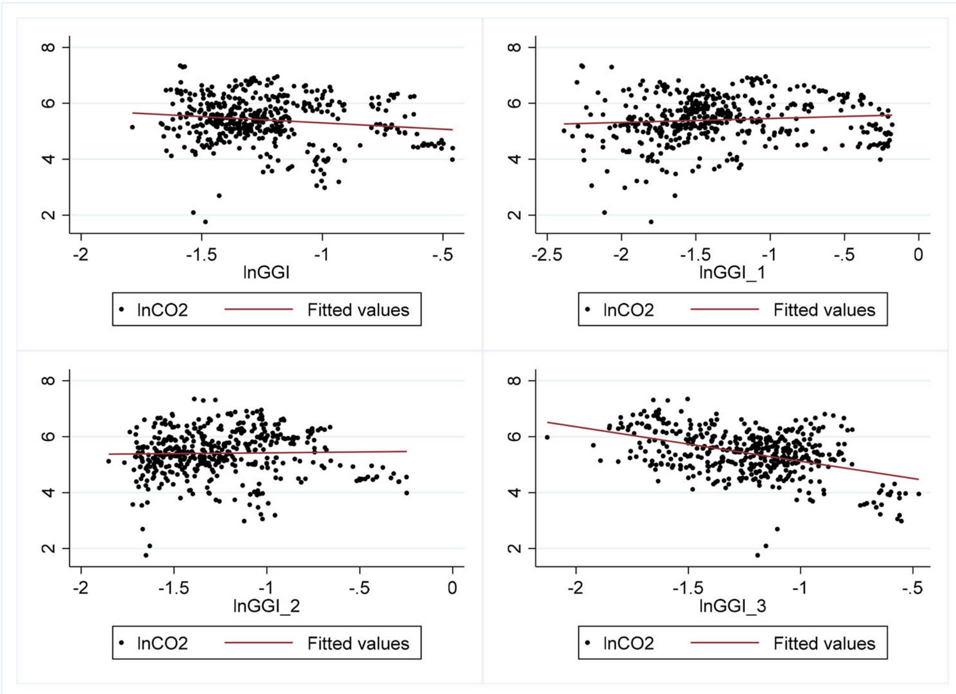

Figure 4. Trend chart of the correlation between green growth and CO_2 emissions.
Source: Self-calculated.

ln*GGI*) and carbon emissions (i.e., $\ln CO_2$) is −0.1463; in other words, green growth and carbon emissions exhibit a significant negative relationship. Based on this, we draw the scatter plot between green growth and carbon emissions (see Figure 4). Both correlation check and scatter plot verify a preliminary conclusion: China's green growth can help mitigate the greenhouse effect.

5.2. Benchmark estimates

In this section, various empirical strategies are employed to discuss the specific impact of green growth on the greenhouse effect in China. The first two columns of Table 3 present the results in the green growth-CO_2 nexus based on the pooled ordinary least squares (OLS) and feasible generalized least squares (FGLS) techniques. Considering that the panel sample may have potential heteroscedasticity and sequence correlation, the estimated results of FGLS strategy are applied as the benchmark estimates. We can find that the results of the inter-group heteroscedasticity test (i.e., Wald test), intra-group autocorrelation test (i.e., Wooldridge test), and inter-group contemporaneous correlation test (i.e., BP LM test) all reject the null hypothesis at the 1% significance level, which implies that the findings of the FGLS estimate are accurate and effective. The coefficient of green growth (i.e., ln*GGI*) is −0.216; an increase in green growth by 1% can mitigate the greenhouse effect by 0.216%. This finding suggests that continuing to advocate green growth and strengthening the evolution of the green economy play an important role in reducing CO_2 emissions.

Table 3. Estimated results of the impact of green growth on CO_2 emissions.

	CO_2 emissions		Per capita CO_2 emissions	
Variable	Pooled OLS	FGLS	Pooled OLS	FGLS
ln*GGI*	−0.804***	−0.216***	−0.701***	−0.278***
	(−2.73)	(−5.96)	(−6.71)	(−7.01)
ln*GFI*	−0.901***	−0.238***	0.147**	−0.004
	(−6.10)	(−6.11)	(2.29)	(−0.13)
ln*EE*	−0.335***	−0.468***	−1.187***	−1.149***
	(−3.42)	(−9.26)	(−28.56)	(−35.61)
ln*ISU*	−0.563***	−0.402***	−0.119***	−0.157***
	(−5.05)	(−13.04)	(−2.60)	(−5.82)
ln*Pgdp*	1.006***	0.832***	1.210***	1.151***
	(10.34)	(28.29)	(29.60)	(46.80)
ln*Tra*	0.256***	0.016	−0.010	−0.019*
	(4.03)	(1.32)	(−0.43)	(−1.77)
ln*Gap*	0.222	−0.353***	0.100	−0.209***
	(0.98)	(−3.78)	(1.05)	(−4.12)
_*Cons*	−7.025***	−3.387***	−15.994***	−14.752***
	(−5.65)	(−11.06)	(−31.23)	(−51.97)
R^2	0.4362		0.8212	
Wald test		4757.90***		4619.32***
Wooldridge test		35.811***		38.068***
BP LM test		2281.18***		752.86***
Obs.	450	450	450	450

Note: ***, **, and * refer to statistical significance at the 1%, 5%, and 10% levels, respectively; the values in parentheses for pooled OLS represent the t-statistics, while the values in parentheses of FGLS estimates indicate the z-statistics.
Source: Self-calculated.

As the goal of carbon neutrality continues to be advocated, the government, the market, and the public are attaching increasing importance to ecological environmental protection and green evolution. More specifically, the government actively formulates relevant laws and regulations to enforce environmental protection activities from the perspective of policy, and restrain the polluting behaviors of enterprises and the public (Zhao et al., 2020). For instance, policies and strategies such as forcibly shutting down high-polluting chemical or manufacturing enterprises and restricting traffic with odd and even numbers have effectively improved greenhouse gas emissions. Moreover, local governments will provide financial support and technical guidance for enterprises' green innovation activities, thus motivating the whole society to gradually shift from focusing on the economy to the coordinated development of the economy and the environment. The national government will also provide corresponding infrastructure for the green transition of the national economy, such as 'coal to gas' and 'coal to electricity,' which effectively addresses massive pollution emissions (Xu & Ge, 2020).

As Wang and Shao (2019) stress, in addition to the joint action of the government and the market, improving public awareness of environmental protection is also an effective means of accelerating green economic development in China. In recent years, with the widespread popularization of the concept of environmental protection and the increasing level of public education, residents have gradually realized the harm caused by the deterioration of the ecological environment and will contribute to China's goal of carbon neutrality by restricting their behavior and using green energy such as electricity, especially in rural areas. Through joint cooperation between the government, enterprises, and the public, China's green economic growth has achieved initial results, which can effectively contribute to the realization of the vision of carbon neutrality.

It is notable that the coefficient of green finance is −0.238, which suggests that China's green finance is negatively associated with the greenhouse effect, which is also reached by Rasoulinezhad and Taghizadeh-Hesary (2022). Green finance refers to the gradual change of financial institutions from profit-oriented to providing funds to support energy saving and pollution reduction projects. This can not only guide the flow of resources from highly polluting industries to technologically advanced sectors, but also provide sufficient capital support for green technological innovation, thereby mitigating the greenhouse effect (Taghizadeh-Hesary et al., 2020).

5.3. Robustness tests

5.3.1. Robustness test 1: Alternative measure of explained variable

In this section, we proceed to check the robustness of the estimated results by using per capita CO_2 emissions (denoted as PCO_2) as explained variable for regression (see the last two columns of Table 3). Obviously, the coefficient values and symbols of the variables are basically consistent with the benchmark regression results. This verifies the reliability of the regression conclusion — the negative green growth-CO_2 nexus.

5.3.2. Robustness test 2: Alternative estimated method

In the last robustness check, we adopted the alternative estimated method — the instrumental variable (IV) approach developed by Lewbel (2012) — to verify the reliability of the carbon-reduction effect of green growth. This method constructs an instrumental variable based on the heteroscedasticity in the error term. The estimation results of Lewbel's (2012) model are reported in Table 4. In this table, the coefficients of green growth (i.e., ln*GGI*) and the ecological environment index (i.e., ln*GGI_3*) are significantly negative, which indicates the robustness and reliability of the benchmark results.

Table 4. Robustness check 2: Alternative estimated method.

Explained variable: lnCO_2

Variable	Model (1)	Model (2)	Model (3)	Model (4)
ln*GGI*	−0.804***			
	(−2.73)			
ln*GGI_1*		0.292*		
		(1.75)		
ln*GGI_2*			0.144	
			(0.81)	
ln*GGI_3*				−0.926***
				(−7.21)
Control variables	Yes	Yes	Yes	Yes
Unc_R^2	0.9876	0.9872	0.9871	0.9890
Hansen J	0.000	0.000	0.000	0.000
Obs.	450	450	450	450

Note: *** and * indicate statistical significance at the 1% and 10% levels, respectively; the values in parentheses indicate t-statistics.
Source: Self-calculated.

5.4. Regional heterogeneous analysis

Due to the differences in population agglomeration, economic development level, resource endowment, and geographical location among China's various provinces, exploring the regional heterogeneity of green growth on CO_2 emissions is necessary. In doing so, following the standard of China's National Bureau of Statistics, we divide the full sample into three regions, i.e., the eastern, central, and western regions; the specific provinces of the three regions are illustrated in Table A4.

Table 5 presents the econometric results of the three regions, which show that only in the central and western regions can green growth affect CO_2 emissions negatively. In eastern region, green growth is not effective in mitigating the greenhouse effect. In Figure 2, the CO_2 emissions in the eastern region are significantly higher than those in the central and western regions. It is difficult for green growth to reduce a large amount of carbon emissions in a short time in areas characterized by rapid economic growth and a high concentration of population and resources. However, in the central and western regions, the economic level is relatively backward, especially in the western region. Under the premise of relatively low carbon emissions, when green growth is vigorously advocated, the constraints of corporate polluting emissions and green technical innovation can effectively alleviate the greenhouse effect.

In contrast to green growth, green finance is negatively associated with carbon emissions in the eastern and central regions, while in the western region, green finance is not conducive to alleviating the greenhouse effect. This finding correlates significantly with the level of financial development between regions. The coefficients of green finance in the eastern and central regions are −1.511 and −0.239, respectively, which suggests that the mitigation effect of green finance development in the

Table 5. Estimated results of regional heterogeneity.

Explained variable: lnCO_2

Variable	Eastern region	Central region	Western region
ln*GGI*	1.451***	−0.169**	−0.761***
	(13.67)	(−2.10)	(−11.31)
ln*GFI*	−1.511***	−0.239***	0.121*
	(−25.43)	(−4.17)	(1.77)
ln*EE*	−0.977***	−0.751***	−0.042
	(−12.27)	(−10.13)	(−0.79)
ln*ISU*	−0.786***	−0.093*	−0.188***
	(−15.44)	(−1.95)	(−3.48)
ln*Pgdp*	1.522***	0.988***	0.564***
	(23.80)	(21.34)	(11.81)
ln*Tra*	−0.199***	0.002	0.067***
	(−5.00)	(0.08)	(3.67)
ln*Gap*	1.087***	0.289	−0.352***
	(7.34)	(1.62)	(−2.95)
_*Cons*	−11.694***	−5.263***	−0.781
	(−17.11)	(−10.58)	(−1.35)
Wald test	278.05***	1668.25***	89.33***
Wooldridge test	3.987*	166.277***	154.02***
BP LM test	302.94***	2283.34***	825.71***
Obs.	165	120	165

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively; the values in parentheses indicate z-statistics.
Source: Self-calculated.

eastern region on carbon emissions is significantly better than that in the central region. Due to the limitation of the level of economic growth, the completeness of financial institutions and systems and the development of financial inclusion show a significant weakening trend from east to west.

6. Further discussion on the mediating role of green finance

6.1. Empirical model

In the benchmark regression, we can find that, at present, the development of green finance plays an important role in reducing CO_2 emissions. In this regard, an interesting question ignites our consideration: Will green finance have an impact on the linkage between green growth and CO_2 emissions? In other words, is green finance an effective mediating variable in the green growth-carbon emissions nexus? To solve this issue, we apply the mediation effect model to discuss the direct and indirect effect of green growth on CO_2 emissions; the specific estimated equations of this model are presented as follows:

$$\ln CO_{2it} = \varphi_0 + \varphi_1 \ln GGI_{it} + \sum_{k=2}^{6} \varphi_k \ln Z_{it} + \nu_i + \mu_t + \varepsilon_{it} \quad (2)$$

$$\ln GFI_{it} = \xi_0 + \xi_1 \ln GGI_{it} + \sum_{k=2}^{6} \xi_k \ln Z_{it} + \nu_i + \mu_t + \varepsilon_{it} \quad (3)$$

$$\ln CO_{2it} = \alpha_0 + \alpha_1 \ln GGI_{it} + \alpha_2 \ln GFI_{it} + \sum_{k=3}^{7} \alpha_k \ln Z_{it} + \nu_i + \mu_t + \varepsilon_{it} \quad (4)$$

where φ_0 and ξ_0 refer to the constant terms, and $\varphi_k(k = 1, 2, \ldots, 6)$ and $\xi_k(k = 1, 2, \ldots, 6)$ represent the estimated parameters. Z denotes ln*Pgdp*, ln*EE*, ln*ISU*, ln*Tra*, and ln*Gap*. Other variables and parameters are consistent with Eq. (1). In these three equations, the coefficient of green growth in Eq. (2) (i.e., φ_1) indicates the total effect of green growth on CO_2 emissions. Only when φ_1 is significant can we further check the direct and indirect effects in the green growth-CO_2 nexus. The coefficient of green growth in Eq. (4) (i.e., α_1) represents the direct effect of green growth on CO_2 emissions. Furthermore, if the coefficients of green growth in Eq. (3) (i.e., ξ_1) and green finance in Eq. (4) (i.e., α_2) are both significant, an indirect effect exists; in other words, green growth can have an impact on carbon emissions by affecting green finance.

6.2. Empirical findings and discussion

The empirical results of estimating Eqs. (2)–(4) based on the FGLS and pooled OLS strategies are presented in Table 6 simultaneously. Models (1)–(3) correspond with the estimation results of Eqs. (2)–(4), respectively. To be more specific, in Model (1),

Table 6. Estimated results of the mediation analysis.

	FGLS estimation			Pooled OLS estimation		
Variable	Model (1)	Model (2)	Model (3)	Model (1)	Model (2)	Model (3)
ln*GGI*	−0.277***	0.202***	−0.216***	−1.128***	0.360***	0.804***
	(−5.62)	(5.48)	(−5.96)	(−3.94)	(7.21)	(−2.73)
ln*GFI*			−0.238***			−0.901***
			(−6.11)			(−6.10)
ln*EE*	−0.397***	−0.085***	−0.468***	−0.161*	−0.194***	−0.335***
	(−9.23)	(−2.64)	(−9.26)	(−1.73)	(−6.66)	(−3.42)
ln*ISU*	−0.356***	0.183***	−0.402***	−0.878***	0.350***	−0.563***
	(−9.45)	(6.53)	(−13.04)	(−7.51)	(13.46)	(−5.05)
ln*Pgdp*	0.741***	0.169***	0.832***	0.822***	0.204***	1.006***
	(24.08)	(4.44)	(28.29)	(8.66)	(7.32)	(10.34)
ln*Tra*	−0.005	0.073***	0.016	0.139**	0.130***	0.256***
	(−0.26)	(6.78)	(1.32)	(2.17)	(9.11)	(4.03)
ln*Gap*	−0.341***	0.077	−0.353***	0.146	0.084	0.222
	(−3.07)	(1.18)	(−3.78)	(0.65)	(1.08)	(0.98)
_*Cons*	−2.256***	−2.772***	−3.387***	−4.461***	−2.845***	−7.025***
	(−6.11)	(−6.41)	(−11.06)	(−3.76)	(−8.00)	(−5.65)
Wald test	4873.75***	1327.77***	4757.90***			
Wooldridge test	35.973***	47.293***	35.811***			
BP LM test	2271.46***	1409.09***	2281.18***			
R^2				0.3870	0.7033	0.4362
Obs.	450	450	450	450	450	450

Note: ***, **, and * refer to statistical significance at the 1%, 5%, and 10% levels, respectively; the values in parentheses for pooled OLS represent the t-statistics, while the values in parentheses of FGLS estimates indicate the z-statistics.
Source: Self-calculated.

the coefficient of green growth is −0.277, which implies the total effect of green growth on CO_2 emissions and emphasizes the effectiveness of China's advocacy for a green economy. The green transformation and growth of China's economy have stimulated the green technological innovation process of enterprises and accelerated the optimization and upgrading of industries. Also, the popularity of the green concept has improved the public's demand for favorable living condition and reduced dependence on high-polluting energy, which can facilitate the reduction of carbon emissions.

The results of estimating Eq. (3) (i.e., Model (2)) indicate that the coefficient of green growth is 0.202, and a 1% increase of green growth accelerates the development of green finance by 0.202%. The active publicity and vigorous advocacy of the green economy by the local government has triggered the response of the whole society to the green concept, and all walks of life have accelerated their transformation to cope with the impact of national policies. Obviously, the financial industry is no exception. Financial institutions gradually incorporate environmental assessment in the process and attach importance to the favorable ecological environment and the development of green industry in investment and financing.

Regarding the third column, the coefficient of green growth (i.e., ln*GGI*) is −0.216. This implies the direct effect of green growth on CO_2 emissions. In addition, the parameter of green finance (i.e., ln*GFI*) is significant. Notably, the significance of ξ_1 and α_2 imply the mediating effect in the green growth-CO_2 nexus. The coefficients of green growth in the second column and green finance in the third column are 0.202 and −0.238, respectively, therefore, $\xi_1 * \alpha_2 = 0.202 * (-0.238) = -0.048076,$ and the contribution of the indirect effect in the total effect is (-0.048076)/(-0.277)=17.36%.

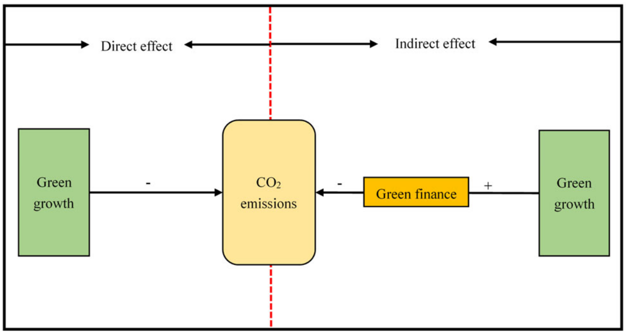

Figure 5. The influence mechanism between green growth and CO_2 emissions.
Source: Self-calculated.

Hence, as an important channel, green finance plays an effective mediating role in the green growth-CO_2 nexus.

In summary, we can conclude that the evolution of green growth not only directly mitigates the greenhouse effect, but also weakens China's carbon emissions by accelerating the development of green finance. The specific influence mechanism on the green growth-CO_2 emissions is presented in Figure 5.

7. Conclusions and policy implications

7.1. Conclusions

To empirically check the actual situation of China's advocacy of green growth on the greenhouse effect, we examine the potential role of green growth in China based on provincial sample data from 2004 to 2018. The regional heterogeneity and how green finance affect the green growth-CO_2 nexus are also discussed in this study. The main findings are illustrated as follows:

1. The primary finding of our study is related to the green growth-CO_2 nexus. The estimated results illustrate that China's current green growth is negatively associated with CO_2 emissions; in other words, the evolution of China's green growth can facilitate carbon emission reduction. From the estimated results of the sub-indexes, we can find that the negative green growth-CO_2 emissions nexus is mainly due to the improvement of the ecological environment.
2. Significant regional heterogeneity exists between China's green growth and carbon emissions. Specifically, only in the central and western regions can green growth effectively facilitate carbon emission reduction, while in the eastern region, a positive link exists between green growth and CO_2 emissions. In addition, green finance can reduce CO_2 emissions in the eastern and central regions, while in the western region, green finance is not conducive to mitigating the greenhouse effect.
3. The findings of the mediating effect model show that the evolution of China's green growth not only alleviates the greenhouse effect directly, but also can facilitate carbon reduction by accelerating the development of green finance.

7.2. Policy implications

Following the above-discussed estimation findings, this study proposes a series of policy implications. First, regarding the negative green growth-CO_2 nexus, it is crucial to continue to strengthen the green transition of China's current economic structure. Local governments should strengthen green and low-carbon development planning, fully integrate the carbon emissions-reduction goal into long-term planning for socio-economic development by formulating relevant laws and regulations, and incorporate green economic development into top-level design from a policy perspective. This measure is applicable to any country in the world, and the vigorous advocacy of national policies is an effective guarantee for enterprises and residents to improve environmental awareness. Moreover, optimizing the regional layout of green and low-carbon transition is an effective means of promoting green growth. Local governments should strengthen the guidance and task requirements of green development in the implementation of major regional strategies such as the coordinated development of Beijing-Tianjin-Hebei, the integrated development of the Yangtze River Delta, and the development of the Yangtze River Economic Belt.

Second, the estimated findings underscore the negative impact of green finance on CO_2 emissions; thus, accelerating the development of green finance is crucial, which is also applicable to other countries. On the one hand, financial institutions such as commercial banks should pay more attention to green finance, fully recognize the importance of green finance development, and speed up the construction of supporting a green finance policy system. Local governments should introduce corresponding policies as soon as possible and clarify the binding indicators for the development of green finance, such as social responsibility and industry standards. On the other hand, continuous innovation of new financial instruments in line with the development of green finance, such as green bonds, green credit, and green insurance, can provide diversified and flexible financing channels that will facilitate the development of green finance and accelerate the mitigation of the greenhouse effect. Vigorously supporting the greening of financial institutions is an effect means for any country to save energy and reduce emissions, which will not only significantly curb the outbreak of financial crisis, but also help achieve the goal of carbon neutrality.

Third, the existence of regional heterogeneity implies that formulating strategies suitable for green growth according to local conditions is key to comprehensively enhancing the green transition of China's economy. For instance, in the economically developed eastern region, green growth cannot effectively alleviate the greenhouse effect due to the large amount of carbon emissions, while green finance is an effective measure; accordingly, provinces in the eastern region should continue to improve green financial institutions and systems, and strengthen the green technological innovation of enterprises. On the contrary, in the central and western regions whose economic development is relatively backward, the carbon emission-reduction effect of green growth has achieved initial results. It is necessary to continue to strengthen green investment and provide financial support for environmental protection technologies.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix A

Table A1. The specific descriptions of the literatures related to growth-CO_2 nexus.

Literature	Relationship	Country	Method	Sample data	Conclusion
Acheampong (2018)	Economic growth and CO_2	116 countries	Panel vector autoregression (PVAR) and Sys-GMM	1990-2014	Bidirectional relationship
Chen et al. (2016)	Economic growth and CO_2	170 countries	Vector Error-Correction Model (VECM)	1980-2011	Positive effect
Mikayilov et al. (2018)	Economic growth and CO_2	Azerbaijan	Johansen, ARDLBT, DOLS, FMOLS, and CCR methods	1992-2013	Positive effect
Shahbaz et al. (2018)	Economic growth and CO_2	Japan	ARDL model	1970-2014	Positive effect
Wang et al. (2018)	Economic growth and CO_2	BRICS countries	Partial least square regression model	1996-2015	Positive effect
Gorus and Aydin (2019)	Economic growth and CO_2	Eight oil-rich MENA countries	Single- and multi-country Granger causality test	1975-2014	No causal relationship
Salahuddin et al. (2016)	Economic growth and CO_2	OECD countries	Pedroni panel cointegration and pooled mean group (PMG)	1991-2012	No causal relationship
Hao et al. (2021)	Green growth and CO_2	G7 countries	Cross-Sectionally Augmented Auto-regressive Distributive lag (CS-ARDL	1991-2017	Negative effect
Chien et al. (2021)	Green growth and CO_2	United States	Quantile autoregressive distributed lag (QARDL) method	1970-2015	Negative effect
Alper and Oguz (2016)	Green growth and CO_2	EU member countries	Asymmetric causality test and autoregressive distributed lag (ARDL) methods	1990-2009	Negative effect
Guo et al. (2017)	Green growth and CO_2	China	Structural equation modeling (SEM)	2011-2012	Negative effect

Source: Self-summarized according to the literatures.

Table A2. The indicator system of green finance in China.

Dimension	Specific indicators	Measure	Code	Property
Economy	Per capita GDP	GDP/population	x1	+
	Per capita disposable income	Disposable income/population	x2	+
	Unemployment rate	Unemployed/total labor force	x3	−
Finance	Per area banks	Amount of banks/areas	x4	+
	Per area bank staff	Amount of bank staff/areas	x5	+
	Per capita banks	Amount of banks/population	x6	+
	Per capita bank staff	Amount of bank staff/population	x7	+
	Deposits	Deposits/GDP	x8	+
	Loans	Loan/GDP	x9	+
	Density of insurance	Premium/population	x10	+
	Depth of insurance	Premium/GDP	x11	+
Environment	The rate of wastewater	Wastewater/(deposit + loan)	x12	−
	The rate of sulfur dioxide	Amount of sulfur dioxide/(deposit + loan)	x13	−
	The rate of solid waste	Amount of solid waste/(deposit + loan)	x14	−
	The rate of energy consumption	Amount of energy consumption/(deposit + loan)	x15	−
	The rate of nature reserve	Amount of nature reserve/(deposit + loan)	x16	+
	The rate of forest	Amount of forest/(deposit + loan)	x17	+

Source: Self-summarized according to the Section 4.2.

Table A3. The descriptions and data sources of variables used.

Variable	Symbols	Definitions	Sources
CO_2 emissions	CO_2	The amount of CO_2 emissions of each province	CEADs (2019)
Green growth	*GGI*	Green growth composite index	CSY (2019), and CESY (2019)
Green finance	*GFI*	Green finance composite index	CSY (2019), CESY (2019), and China Regional Financial Operation Report (CRFOR)
Economic growth	*Pgdp*	Per capita GDP	CSY (2019)
Energy efficiency	*EE*	The output value per unit of energy consumption, i.e., the reciprocal of energy intensity	CSY (2019)
Industrial structure upgrading	*ISU*	The ratio of the output value of tertiary industry to the output value of secondary industry	CSY (2019)
Trade openness	*Tra*	The proportion of total import and export trade in GDP in each province	CSY (2019)
Income inequality	*Gap*	The proportion of urban per capita disposable income to rural per capita disposable income	CSY (2019)

Source: Self-summarized according to the selected variables.

Table A4. The specific provinces of the three regions.

Region	Provinces
Eastern region (11 provinces)	Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan
Central region (8 provinces)	Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan
Western region (11 provinces)	Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang

Source: Self-summarized according to the National Bureau of Statistics of China.

Table A5. Abbreviation list.

Abbreviations			
BP	British Petroleum	GTFP	Green total factor productivity
CEADs	China Emission Accounts and Datasets	HDI	Human development index
CESY	China Environment Statistical Yearbook	IEA	International Energy Agency
CO_2	Carbon dioxide	IV	Instrumental variable
COVID-19	Corona virus disease 2019	IWI	Inclusive wealth index
CRFOR	China Regional Financial Operation Report	ML	Malmquist-Luenberger
CS-ARDL	Cross-Sectionally Augmented Auto-regressive Distributive lag	Mt of CO_2	Million tonnes of CO_2
CSY	China Statistical Yearbook	OECD	Organization for Economic Cooperation and Development
DDF	Directional distance function	OLS	Ordinary least squares
DEA	Data envelopment analysis	R&D	Research and development
FGLS	Feasible generalized least squares	UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
GDP	Gross domestic product	VIF	Variance inflation factor