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Is China's green growth possible? The roles of green trade and green energy

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ABSTRACT

In tandem with global initiatives to 'go green', China is undertaking a series of steps to achieve green economic growth. To investigate the dynamic nexus of green growth, green trade, and green energy (3 G) in China, an index is developed in this study to assess the level of provincial green growth by employing five types of indicators – economic growth, environmental pollution loss, carbon emissions loss, natural resource loss, and environmental and natural resource benefits. Then, this paper uses the SYS-GMM method to explore the influences of green trade and green energy on green growth by using data compiled from 30 provinces in China over the period 2007–2016. Furthermore, we check the potential heterogeneity, asymmetry, and internal mediating mechanism of the 3 G nexus. The main findings are highlighted as follows: (1) Green trade and green energy can accelerate China's green growth; (2) enhancing medium- and high-technology green trade can contribute to improving local green growth; (3) this impact is heterogeneous in regions with different trade levels, and asymmetric at various quantiles for the full panel; (4) the positive investment effect, labour effect, and technical effect are effective mediators of the nexus between green trade and green growth.

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1. Introduction

Many countries have experienced remarkable economic growth since the second industrial revolution (Panagiotis et al., 2017; Wang et al., 2022). In recent years, China's rapid economic growth is driven by domestic industrialisation expansion, which relies heavily on burning fossil fuels such as coal (Duan & Yan, 2021; Li et al., 2021a; 2022). China has seen a marked increase in its total energy consumption over the last five years (Song et al., 2022; Zhu et al., 2022). This kind of industrial and energy structure poses challenges relating to the depletion of natural resources and

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degradation of the environment (Dong et al., 2021; Jiang et al., 2020; Ren et al., 2022a). How to balance economic development and environmental issues is an essential problem in China. Green growth refers mainly to the promotion of economic growth under conditions that ensure natural resources and environments can provide services that enhance citizens' well-being and achieve sustainable development without harming the environment and natural resources (Hallegatte et al., 2012; Hallegatte & Corfee-Morlot, 2011; Li et al., 2021b). During COP26 held in November 2021, many countries pledged to achieve global net-zero emissions by the middle of the current century and limit the global rise in temperatures to 1.5 degrees by 2030. With the strong international effort to achieve these goals, countries all over the world have taken up the challenge to accelerate the reduction of carbon emissions and develop green growth (Ren et al., 2021, 2022b; Shahbaz et al., 2022). China is undertaking a series of steps to collaboratively achieve green growth in tandem with global initiatives to 'go green' (Liu et al., 2018, 2021a; Zhao et al., 2021).

There is a global search for green, sustainable, and economically attractive solutions. Studies on green growth are numerous, but no universally standard for measuring green growth exists. Therefore, a more comprehensive evaluation of China's green growth and a clear understanding of China's current situation is extremely important. On the one hand, emerging green product technologies have changed the development trajectory of domestic enterprises, leading to improved quality and efficiency of traded products, enabling them to be more competitive in international markets. The production and use processes of green products always require less energy and produce fewer emissions, and thus, are more environmentally friendly (Sun et al., 2021). Although it is widely accepted that international trade can promote national economic growth (Brini et al., 2017; Gokmenoglu et al., 2015; Rahman, 2021), the relationship between trade in green products and a green economy has not been studied. On the other hand, the transformation towards green energy is considered to be a good solution to the problem of fossil energy depletion and environmental degradation, and therefore attracts worldwide attention (Jiang et al., 2020; Liu et al., 2021b; Qin et al., 2022). Green energy refers to the clean energy generated from natural resources available all over the world, and includes hydro, wind, solar, biomass, and other sources of energy (Bhowmik et al., 2017; Dong et al., 2018; Troster et al., 2018). Since 2006, China has begun to implement a subsidy policy based on electricity prices for renewable energy power generation to accelerate the development of renewable energy. After 2012, subsidies are allocated out of government-managed funds. The 13th Five-Year Plan (2016–2020) in China emphasises the importance of developing green energy in the national energy structure. Furthermore, green energy is regarded as the energy source that can promote sustainable economic development due to its low carbon emissions (Apergis & Payne, 2010; Sadorsky, 2009; Sohag et al., 2019). While literature that focuses on the dynamic nexus among green trade, green energy, and green growth in China is scarce.

This paper first aims to evaluate the green growth in 30 provinces in China between 2007 and 2016. Based on the SYS-GMM method, this paper explores the nexus of green growth, green trade, and green energy (3 G). Furthermore, this study checks the potential heterogeneity, asymmetry, and internal mediation impact mechanism of the 3 G nexus. The study makes three important contributions to the literature: (1) We provide a new and reliable method for assessing provincial green growth. This is pretty important for comprehensively understanding the variation of green growth, green trade, and green energy nexus. (2) This paper is the first attempt to explore the dynamic 3 G nexus in China. Accordingly, this can benefit policy-makers in China not only by helping them devise policies to accelerate local green growth, but also by helping them rationally adjust the energy structure and international trade structure. (3) this paper explores the potential heterogeneity and asymmetry of the impacts of green trade and green energy on green growth. We further check the internal mediation impact mechanism (i.e., investment, labour, and technical effects) of the impacts of green trade on green growth. This will not only facilitate an understanding of the differences in the technical levels of products and the provinces and the 3 G nexus, but will also provide local governments with new evidence to formulate specific policies to improve green growth, green trade, and green energy simultaneously.

Below is a summary of the rest of the study. Section 2 presents a review of the literature. Section 3 assesses the indicators of green growth. The model and data sources are described in Section 4. Section 5 shows the benchmark regression and the heterogeneous analysis. Section 6 presents further discussions, including asymmetric analysis and mediation analysis. Section 7 outlines the policy implications and conclusions.

2. Literature review

2.1. Green growth

Since green growth gain increasing attention over the past few years, many scholars focus on identifying actual and concrete green growth. Some studies analyse green growth from the perspective of production efficiency (Lin et al., 2013; Lin & Zhou, 2021; Wu et al., 2020; Xie et al., 2018; Zhao et al., 2021; Zhu et al., 2020). Most of them argue that green growth reduces unexpected output while improving desirable output. For instance, Zhao et al. (2020) employ a super-SBM model to measure green economic efficiency in China. Some scholars also take green GDP as representative of the green economy (Li & Fang, 2014; Talberth & Bohara, 2006), which deducts environmental costs from traditional GDP (Kunanuntakij et al., 2017).

As for the concept of green growth and the factors considered in the existing literature, the core concept of green growth, according to Jacobs (2012), is economic development through environmental protection. Furthermore, Green growth should be measured in terms of economic growth, job creation, and environmental improvement, according to Reilly (2012). Jouvet and Perthuis (2013) provide a stricter concept of green growth – green growth involves altering production and consumption processes to maintain or restore these regulatory functions of natural resources capital. Sohag et al. (2019) propose a method for green growth and use it to measure green growth in Turkey. Specifically, green growth is defined as sustainable economic growth after deducting the damage caused by natural resource exploitation and greenhouse gas. Lin and Zhou (2021) also consider carbon emissions intensity when constructing a comprehensive indicator system of green growth in China. Besides, they propose that water pollution, air pollution, and green space are also important indicators that need to be considered (Lin & Zhou, 2021).

2.2. Green growth-trade-energy (3 G) nexus

The second part focuses mainly on the nexus of 3 G. A focus of trade research has always been the nexus of trade and economic growth. Explanations among the existing studies of the mediation channels from international trade on economic growth include three main aspects: (1) The foreign exchange income brought by export trade and fixed assets formed by importing advanced equipment accelerate capital accumulation, thereby promoting economic growth (Jones & Manuelli, 1990); (2) the human capital accumulation effect of trade can improve the human capital of trading countries and enhance the absorption capacity of foreign advanced technology, therefore improving economic growth (Grossman & Helpman, 1991; Young, 1991); (3) trade will lead to a technology spill-over effect through imitation and other behaviours to improve the technological levels of importing countries, thereby promoting economic growth (Grossman & Helpman, 1991).

Another focus of this paper is the influence of green energy on green growth. Sources of green energy include hydro, wind, solar, and biomass. Political, economic, social, and technological factors jointly influence the development of green energy (Biresselioglu et al., 2018; Wüstenhagen et al., 2007). Green energy is regarded as the energy source that can promote sustainable economic development because it has zero or very little carbon emissions in the energy-production process (Sohag et al., 2019). Furthermore, some scholars suggest that increasing the production of green energy can reduce pressure on the regional balance of payments, increase income per capita, and achieve sustainable economic growth (Apergis & Payne, 2010; Sadorsky, 2009). Besides, the development of green energy is impervious to the geopolitical risks of fossil energy exporters and the depletion of local natural resources, which can ensure global energy security and is a suitable solution for achieving carbon neutrality (Elliot, 2007; Ferguson, 2007; Menegaki, 2011; Sohag et al., 2019).

2.3. Literature gaps

Despite the extensive literature on green growth, there is no universally agreed standard for measuring green growth. Therefore, a more comprehensive evaluation of China's green growth and a clear understanding of China's current situation is extremely important. Besides, it is important to consider the development trend and distribution of green growth. As far as we know, few scholars have measured the level of provincial green trade in China, and studies that focus on the nexus of green trade and green growth are scarce. Despite the fact that some researchers focus on the nexus between sustainable economic development and green energy, the literature on the 3 G nexus is rather scanty. Additionally, the regional heterogeneous, symmetric, and internal mediation impact mechanism of the 3 G nexus is conducive to making policies that take regional differences into consideration. Accordingly, this study proposes two hypotheses as follows.

Hypothesis 1: Green trade and green energy can accelerate green growth.

Hypothesis 2: The indirect influences of green trade on green growth mainly through the investment effect, labour effect, and technical effect.

3. Assessing green growth in China

The goals of green growth include two aspects: developing the economic level and improving environmental quality (Jouvet & Perthuis, 2013; Song et al., 2019). Given that there is no uniform standard in the existing literature for measuring green growth, China's green growth is measured in this study by combining the methodology of some scholars and global organisations. In general, green growth (*GGR*) includes five types of indicators: economic growth (*GDP*), environmental pollution loss (*VEP*), carbon emissions loss (*VCE*), natural resource loss (*VNR*), and environmental and natural resource benefits (*EBE*). The definition of *GGR* is as follows:

$$GGR_{i,t} = GDP_{i,t} - VEP_{i,t} - VCE_{i,t} - VNR_{i,t} + ENB_{i,t} \tag{1}$$

1. **Environmental pollution loss**

The value of environmental pollution loss usually includes two aspects: the monetary value of air pollution emissions loss and water pollution emissions loss. The loss values per unit of air and water pollution emissions can be represented by pollution discharge fees. The monetary value of environmental pollution loss (*VEP*) is obtained as follows:

$$VEP_{i,t} = APO_{i,t} \cdot P_{1i,t} + WPO_{i,t} \cdot P_{2i,t} \tag{2}$$

where i and t represent the provinces and years, respectively. *APO* denotes air pollution, P_1 is the price of air pollution, *WPO* indicates water pollution, and P_2 is the price of water pollution emissions. This study takes SO_2 and COD emissions to represent *APO* and *WPO* (as SO_2 and COD are two major and typical emissions of air and water pollution emissions), respectively. The price data of pollution discharge fees are obtained from the NDRC (2020). Specifically, the monetary pollution loss values per unit of SO_2 and COD emissions are 12 RMB/kg and 14 RMB/kg, respectively. Furthermore, the data of *APO* and *WPO* are from the CSY (2020).

2. **Carbon emissions loss**

The monetary value of carbon emissions loss (*VCE*) accounting is obtained as follows:

$$VCE_{i,t} = CO_{2i,t} \cdot \gamma_{i,t} \cdot P_{3i,t} \tag{3}$$

where CO_2 denotes the amount of carbon emissions, γ represents the exchange rate, and P_3 is the carbon taxes rate. Europe is one of the most mature parts of the world for the carbon taxes mechanism. Considering the current situation of carbon emissions reduction stress in China, this study chooses the carbon taxes rate of Sweden (i.e., the price per unit of CO_2 emissions adopted 139 USD/tons in 2018), which is relatively higher in the existing global carbon taxes rate, as P_3 (World Bank, 2018). The carbon taxes rate is converted into RMB according to the average annual exchange rate of the USD. The data on CO_2 emissions is obtained from CEAD (2018).

3. **Natural resource depletion loss**

The value of natural resource depletion loss (*VNR*) accounting usually includes two aspects: the monetary value of water resource depletion loss (*WRD*) and energy resource depletion loss (*ERD*), and can be defined as follows:

$$\begin{aligned} VNR_{i,t} &= WRD_{i,t} + ERD_{i,t} \\ &= WPR_{i,t} \cdot TWC_{i,t} + TEC_{i,t} \cdot PER_{i,t} \\ &= [(OVW_{i,t}/WRE_{i,t}) \cdot \alpha_{i,t}] \cdot (WCP_{i,t} \cdot RPO_{i,t}) + TEC_{i,t} \cdot PER_{i,t} \end{aligned} \tag{4}$$

where *WPR* denotes the price of water, and *TWC* indicates total water consumption. *WPR* is estimated in an internationally accepted method – $(OVW_{i,t}/WRE_{i,t}) \cdot \alpha_{i,t}$. *OVW* is the output value in the water industry, which is roughly evaluated by provincial GDP due to data limitations. *WRE* indicates the total amount of water resources, α denotes the willingness of consumers to pay for water consumption. This coefficient is recommended to be $1\% - 3\%$, due to the water shortage China is currently facing, and α is assumed to be 3% in this study (Song et al., 2019). The value of *TWC* is obtained through the expression $WCP_{i,t} \cdot RPO_{i,t}$. Besides, *WCP* is the water consumption per capita, and *RPO* denotes the resident population. Furthermore, *TEC* is total energy consumption, and *PER* denotes the price of the energy resource (i.e., 1,133 RMB/ton of standard coal). The original data of *OVW*, *WRE*, *WCP*, *RPO*, and *TEC* used in this study are obtained from the CSY (2020).

4. **Environmental and natural resource benefits**

The value of environmental and natural resource benefits can be classified into four aspects in this study: the value of SO_2 absorbed (*VSA*), dust removal (*VDR*), carbon sequestration (*VCS*), and investment in industrial pollution control (*IPC*). Following Song et al. (2019), the industrial SO_2 absorption cost, dust removal cost, and carbon sequestration cost of green space are used to replace the economic value of *VSA*, *VDR*, and *VCS*, respectively. The *ENB* can be calculated as follows:

$$\begin{aligned} ENB_{i,t} &= VSA_{i,t} + VDR_{i,t} + VCS_{i,t} + IPC_{i,t} \\ &= GSA_{i,t} \cdot \varphi_{i,t} \cdot \eta_{i,t} + GSA_{i,t} \cdot \beta_{i,t} \cdot \delta_{i,t} + GSA_{i,t} \cdot \gamma_{i,t} \cdot P_{3i,t} + IPC_{i,t} \end{aligned} \tag{5}$$

where *GSA* represents green space area, φ denotes the annual average SO_2 absorbed capacity of urban green space (i.e., 0.296 ton/hm^2), η is the unit reduction cost of the SO_2 absorption amount (i.e., 600 RMB/ton), β denotes the annual dust capacity of

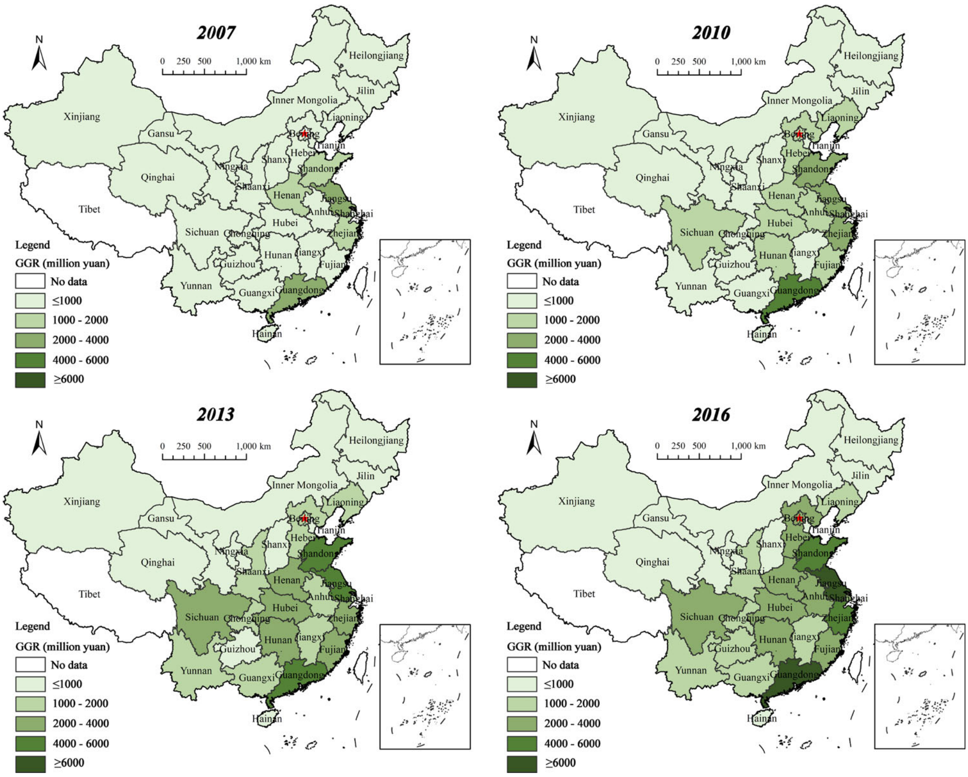

Figure 1. Spatial distribution of *GGR* for selected years.
Source: Self-Calculated following Section 3.

green space (i.e., 10.9 ton/hm^2), δ is the dust removal cost (i.e., 170 RMB/ton), γ represents the exchange rate, and P_3 is the carbon taxes rate. The data of *GSA* and *IPC* are derived from the CSY (2020).

Figure 1 shows the green growth calculated in this study. From this figure, one can see that the green growth index in southern China presents a significant strengthening trend from 2007 to 2016. The provinces with high *GGR* are mainly located in the southeastern coastal areas; and the provinces with low *GGR* are in the northwest areas. For instance, Jiangsu, Guangdong, Zhejiang, and Shandong have experienced high green growth in the past decade. Furthermore, in the northwest regions, such as Gansu, Qinghai, Ningxia, and Xinjiang, a lower level of green growth is found. The main reason for this phenomenon may be the relatively lower level of economic development.

4. Models and data

4.1. Empirical model

To explore the influences of green trade and green energy on *GGR* in China, this study takes green trade and green energy as the core explanatory variables, and green growth as the explained variable. Furthermore, this study introduces control variables, including financial development, urbanisation rate, energy structure, and industrial structure upgrading. The dynamic multivariate framework can be defined as follows in this study:

$$GGR_{i,t} = f(GGR_{i,t-1}, GTR_{i,t}, GEN_{i,t}, FD_{i,t}, UR_{i,t}, ES_{i,t}, ISU_{i,t}) \tag{6}$$

where i and t represent the provinces and years, respectively. *GGR* denotes green growth, *GTR* is green trade, *GEN* denotes green energy, *FD* represents financial development, *UR* is urbanisation rate, *ES* represents energy structure, and *ISU* denotes industrial structure upgrading. To avoid fluctuations in the data and eliminate potential heteroscedasticity, all the variables are logarithmically processed. Therefore, the model can be defined as follows:

$$LnGGR_{i,t} = \alpha_0 + \alpha_1 LnGGR_{i,t-1} + \alpha_2 LnGTR_{i,t} + \alpha_3 LnGEN_{i,t} + \sum_{k=4}^{7} \alpha_k LnX_{k,i,t} + \tau_{i,t} \tag{7}$$

where α_0 is the intercept term, α_1-α_7 are the coefficients of each variable, and X refers to control variables (i.e., *FD*, *UR*, *ES*, and *ISU*).

4.2. Data

To quantitatively analyse the influence of *GTR* and *GEN* on *GGR*, balanced panel data covering 30 provinces in China (i.e., due to data availability, Tibet, Hong Kong, Macau, and Taiwan are excluded) from 2007 to 2016 is employed for empirical analysis in this study. The reason for us to use the study period is that the earliest year for one of the essential indicators of green growth is 2007; and the latest year for the data of green trade, specifically, the CCIED (2017) is 2016. As the dependent variable, the indexes of green growth (*GGR*) are from Section 3. Furthermore, the indexes of green trade (*GTR*), green energy (*GEN*), and control variables are measured as follows.

1. Green trade (*GTR*): A forthcoming study combines the lists of green products of four organisations (i.e., APEC, 2012, UNESCAP, 2011, ICTSD, 2017, World Bank, 2008) to produce a list of 142 green products. The original trade data of trade value are derived from CCIED (2017). *GTR* can be defined as follows:

$$GTR_{i,t} = IMG_{i,t} + EXG_{i,t} = \sum_{f=1}^{F} \sum_{p=1}^{P} (imp_{i,t,p,f} + exp_{i,t,p,f}) \tag{8}$$

   IMG and *EXG* are the green import and export value, *imp* and *exp* are the trade value of each product p in firm f and province i. Furthermore, following Lall (2000), the products are divided into the resource-based and low-technology (*LGT*), medium-technology (*MGT*), and high-technology (*HGT*) level green trade based on the technical level.

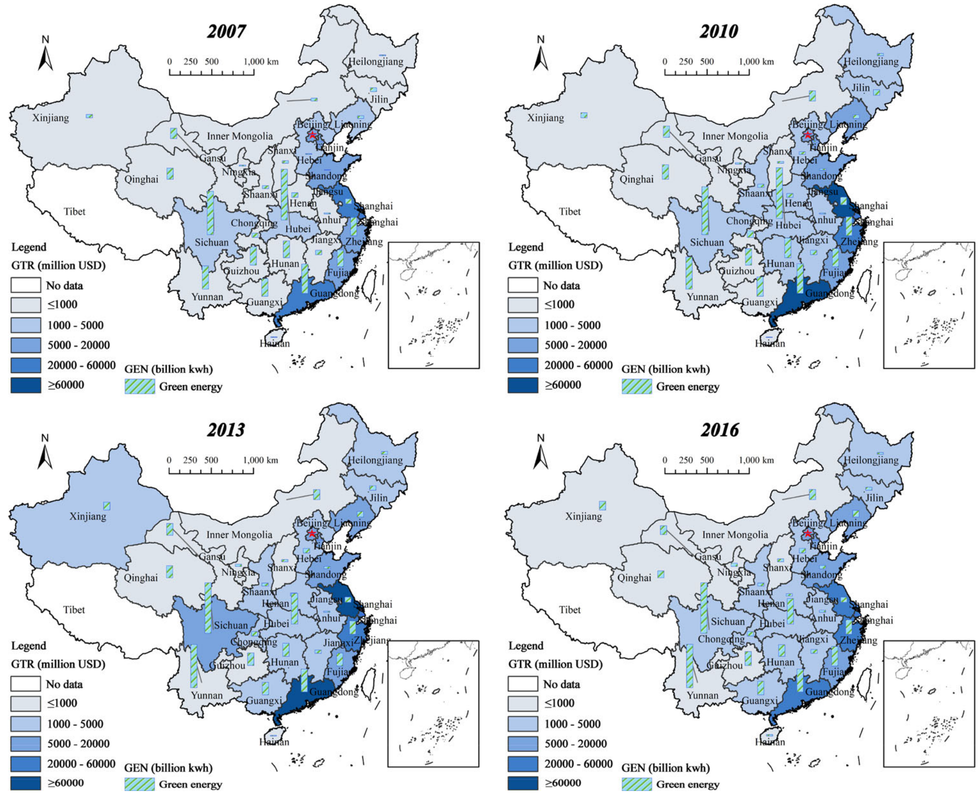

Figure 2. Spatial distribution of *GTR* and *GEN* for selected years.
Source: Self-Calculated according to CCIED (2017) and CSY (2020).

2. Green energy (*GEN*): This paper uses the green energy index mainly to measure the level of provincial renewable energy development. Electricity generated from renewable energy is better for the environment than traditional thermal power, which is generated by burning fossil fuels. Following the work of Wang et al. (2021) and Destek and Aslan (2017), the green energy index can be measured by power generation other than thermal power. The data can be derived from the CSY (2020). This paper further draws the maps of *GTR* and *GEN* indexes (see Figure 2) and China's average *GTR*, *GEN*, *IMG*, and *EXG* (see Figure 3). As can be seen from Figure 2, the green trade value in the eastern region is relatively high, while the green energy development level in the western region is high. From Figure 3, one can see that China's average green energy is growing rapidly during the study period; after a short decline in 2008, average green trade began to rise rapidly from 2009 to 2014, and began to decline for the second time in 2014.
3. Control variables: *FD* is measured by the added value of financial industry, *UR* denotes the ratio of the urban to total population, *ES* represents the ratio of coal to total energy consumption, and *ISU* is the ratio of the added value in tertiary to secondary industry. The data on *FD*, *UR*, *UR*, and *ISU* are from the CSY (2020). Furthermore, the original data of *IMG*, *EXG*, *LGT*, *MGT*, and *HGT* are

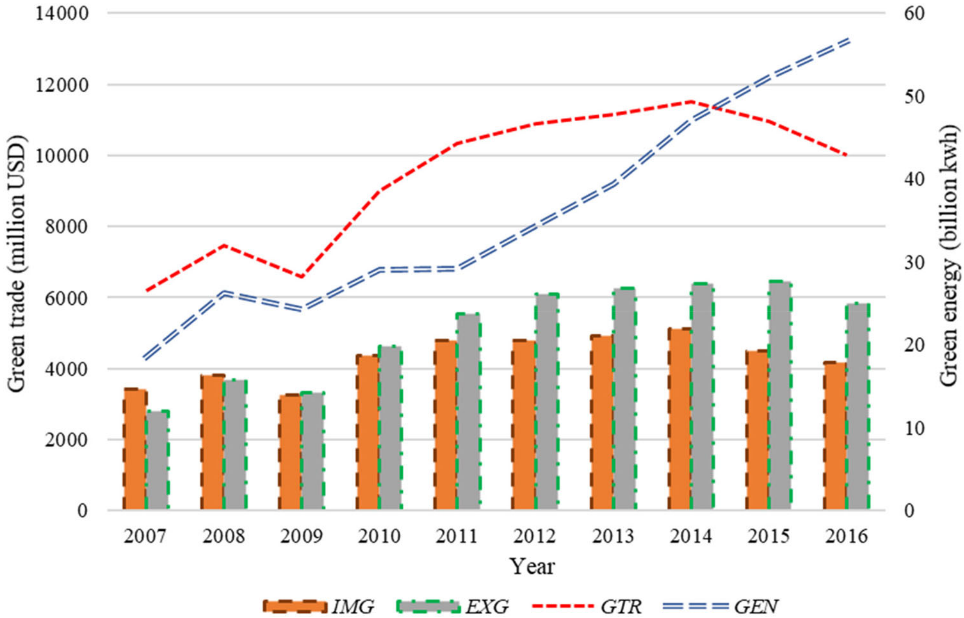

Figure 3. Average *GTR*, *GEN*, *IMG*, and *EXG* of China.
Source: Self-Calculated according to CCIED (2017) and CSY (2020).

Table 1. Descriptive statistics of the variables.

Variable		Mean	Max.	Min.	S. D.
LnGGR	Green growth	13.73908	15.8652	9.775869	1.06528
LnGTR	Green trade	7.644745	11.64318	1.875032	1.810201
LnGEN	Green energy	2.673548	5.661578	−4.2687	1.631956
LnFD	Financial development	6.421532	8.790269	3.299534	1.077966
LnUR	Urbanisation rate	−0.65553	−0.10821	−1.26412	0.2397
LnES	Energy structure	−0.68163	−0.20418	−2.44996	0.361095
LnISU	Industrial structure upgrading	0.018778	1.561889	−0.64046	0.369891
LnIMG	Green import	6.777432	10.83009	1.803053	1.853657
LnEXG	Green export	6.921275	11.05711	−0.90222	2.036908
LnLGT	Resource-based and low-technology	5.484726	9.849836	−1.29802	1.908164
LnMGT	Medium-technology	6.437279	9.439099	1.260103	1.590125
LnHGT	High-technology	6.968708	11.3755	1.001431	2.019344
LnINE	Investment effect	10.12027	13.13967	7.087574	1.418612
LnLAE	Labour effect	2.002817	3.20234	−0.82098	0.861754
LnTEE	Technical effect	9.33395	12.50597	5.402678	1.54503

Source: Self-Calculated.

from the CCIED (2017). The data of investment effect (*INE*), labour effect (*LAE*), and technical effect (*TEE*) are from the CSY (2020). Table 1 shows the interpretation and descriptive statistics for variables.

5. Results and discussions

5.1. Cross-sectional dependence tests

The Pesaran CD test (Pesaran, 2004), and the Frees test (Frees, 2004) are employed in this study to examine the cross-sectional dependence (see Table 2 for the test

Table 2. Results of the cross-sectional dependence tests.

Test	Statistics
Pesaran CD test	3.421***
Frees test	4.490**

Note: Asterisks indicate significance at the 0.1 *** and 0.05 ** levels.
Source: Self-Calculated.

results). In the null hypothesis, panel data are not cross-sectional dependent. One can see that the p-values of the tests in Table 2 are significant, which shows that cross-sectional dependence must be considered; otherwise, it may result in inconsistent estimates.

5.2. Benchmark regression

This paper employs the SYS-GMM method as the benchmark regression to investigate the impacts of green trade and green energy on green growth (Arellano & Bover, 1995). A dynamic panel data estimation method based on SYS-GMM is appropriate for large cross-sectional dependence and short periods. Furthermore, due to that the influencing factors of the green economy are complex in reality, the endogeneity caused by omitted explanatory variables will destroy the consistency of parameter estimation. To a certain extent, this method can also solve estimation bias caused by potential endogeneity. Two static panel data estimation methods, including the FE and RE methods, are also used in this paper to ensure that the benchmark regression results are robust (see Columns (1) and (2) of Table 3). This study employs green imports (*IMG*) and green exports (*EXG*) to replace green trade (*GTR*) to further ensure the robustness of the results; the results are displayed in Columns (3) and (4), respectively. The benchmark regression results are in Column (5) of Table 3. The results in Table 3 show that our empirical results are robust.

One can see from the bottom of Columns (3) – (5) of Table 3, the p-value of the AR (1) is lower than 0.1, and that of the AR (2) is higher than 0.1. These results of A-B tests show that the premise for using the SYS-GMM model is met. Furthermore, the p-value of Sargan tests is higher than 0.1, which indicates that all the instrumental variables are effective. For one of the key independent variables, green trade, the estimated coefficient of *GTR* is positive, which shows that green trade is positively related to green growth. A 1% increase in green trade can promote 0.0569% green growth approximately. Furthermore, combining the estimation results with Columns (3) and (4), one can see that increased green imports and green exports can significantly improve local green growth. For another one of the key independent variables, the gradual increase of green energy (*GEN*) can significantly improve green growth. To be more specific, a 1% increase in green energy can promote green growth by approximately 0.019%. Furthermore, the finding of the benchmark regression confirms the first hypotheses. In terms of *FD*, *UR*, *ES*, and *ISU*, both *FD* and *UR* have a positive impact on green growth, while both the increased *ES* and *ISU* will lead to a decline in green growth.

Table 3. Results of the *GTR*, *GEN*, and *GGR* nexus.

	Static panel estimation		Dynamic panel estimation		
Variable	(1) FE	(2) RE	(3)	(4) SYS-GMM	(5)
$LnGGR_{i,t-1}$			0.733***	0.791***	0.759***
			(48.84)	(60.48)	(58.48)
LnGTR	0.0568***	0.0635***			0.0569***
	(2.86)	(3.28)			(12.56)
LnIMG			0.0647***		
			(18.64)		
LnEXG				0.0150***	
				(5.29)	
LnGEN	0.0415***	0.0458***	0.0276***	0.0141***	0.0190***
	(3.42)	(3.86)	(7.87)	(3.59)	(4.59)
LnFD	0.608***	0.655***	0.138***	0.0729***	0.0845***
	(18.75)	(21.78)	(8.58)	(4.31)	(5.02)
LnUR	0.379**	0.0683	0.108*	0.323***	0.206***
	(2.20)	(0.44)	(1.78)	(6.56)	(3.55)
LnES	−0.146***	−0.123**	−0.206***	−0.329***	−0.280***
	(−2.70)	(−2.31)	(−6.16)	(−8.79)	(−6.66)
LnISU	−0.350***	−0.399***	−0.316***	−0.352***	−0.301***
	(−5.97)	(−7.01)	(−16.40)	(−23.03)	(−14.90)
_Cons	9.442***	8.891***	2.297***	2.373***	2.335***
	(33.37)	(33.21)	(19.70)	(43.29)	(32.41)
AR(1)			0.0506	0.0767	0.0571
AR(2)			0.8063	0.5944	0.7552
Sargan			0.9576	0.9391	0.9420
R^2	0.8414	0.8758			

Notes: Asterisks indicate significance at the 0.01 ***, 0.05 **, and 0.1 * levels.
Source: Self-Calculated.

5.3. Heterogeneous analysis

5.3.1. Products' heterogeneous analysis

In this section, green trade is divided into three types (*LGT*, *MGT*, and *HGT*). This study empirically explores the heterogeneity of the products in terms of the influence of *GTR* on *GGR* (see Table 4). The results of A-B and the Sargan tests are all as expected, which indicates that the SYS-GMM method is suitable for the regression, and all instrumental variables are effective.

One can see from Table 4 that the improvement of *LGT* has no significant impact on green growth, while the increased *MGT* and *HGT* can contribute to green growth in China. A 1% increase in *MGT* can result in a 0.0540% increase in green growth, and a 1% increase in *HGT* can improve green growth by 0.0579%. From these results, we can conclude that upgrading the trade structure and increasing the *MGT* and *HGT* can significantly improve the promotion effect of *GTR* on *GGR*. Besides, the signs and significance of the results of green energy, financial development, urbanisation rate, energy structure, and industrial structure upgrading are all consistent with that in the benchmark regression, which also proves the robustness of the benchmark regression.

5.3.2. Regional heterogeneous analysis

From Figure 2, one can see that significant differences exist in green trade and green energy among the regions in China. This paper further explores the regional heterogeneous influences of green trade and green energy on green growth. The sample is divided into four regions based on the levels of green trade and green energy. Region

Table 4. Results of the products' heterogeneous analysis.

Variable	(1) *LnLGT*	(2) *LnMGT*	(3) *LnHGT*
$LnGGR_{i,t-1}$	0.797***	0.754***	0.768***
	(61.09)	(53.23)	(47.27)
LnLGT	0.000842		
	(0.66)		
LnMGT		0.0540***	
		(16.31)	
LnHGT			0.0579***
			(12.00)
LnGEN	0.0136***	0.0198***	0.0206***
	(3.88)	(6.55)	(5.78)
LnFD	0.0837***	0.117***	0.0739***
	(4.93)	(5.92)	(4.24)
LnUR	0.335***	0.141***	0.193***
	(5.12)	(2.96)	(2.95)
LnES	−0.323***	−0.252***	−0.261***
	(−9.56)	(−8.86)	(−6.11)
LnISU	−0.368***	−0.335***	−0.298***
	(−17.61)	(−18.73)	(−14.56)
_Cons	2.334***	2.255***	2.314***
	(33.55)	(34.44)	(17.29)
AR(1)	0.0795	0.0515	0.0722
AR(2)	0.5728	0.7242	0.7455
Sargan	0.9405	0.9464	0.9483

Notes: Asterisks indicate significance at the 0.01 ***, 0.05 **, and 0.1 * levels.
Source: Self-Calculated.

I refers to regions whose green trade and green energy are higher than the median level (i.e., high GTR and high GEN); Region II refers to regions in which green trade is lower than the median level and green energy is higher than the median level (i.e., low GTR and high GEN); Region III refers to regions in which green trade and green energy are both lower than the median level (i.e., low GTR and low GEN); Region IV refers to regions in which green trade is higher than the median level and green energy is lower than the median level (i.e., high GTR and low GEN). As can be seen from the division results in Figure 4, the results of regional heterogeneous analysis based on the FE method are shown in Table 5.

Table 5 shows that a significant positive impact exists between *GTR* and *GGR* in the high-GEN regions (i.e., Region I and II), while in the low-GEN regions, the impact of green trade is insignificant. Specifically, a 1% increase in *GTR* can significantly improve *GGR* in Regions I and II, by 0.152% and 0.0637%, respectively. From the results, we can conclude that increased *GTR* plays an essential role in *GGR* in regions with high levels of green energy development. Positive impact of *GTR* on *GGR* is greatest in Region I, which also indicates that green trade in Region I needs to be improved. Furthermore, Table 5 shows that the impact of *GEN* on *GGR* is statistically significant in Regions II, III, and IV; while it is insignificant in Region I. Specifically, the estimated coefficients of *GEN* on *GGR* are 0.0817, 0.119, and 0.0267 in Regions II, III, and IV, respectively. Combining the results of regional heterogeneous analysis, in regions with higher levels of *GEN*, it is more effective to improve green products production and enhance the *GTR*; in Regions II, III, and IV, it is essential to accelerate the local green energy industry development to improve *GGR*. As for the control variables, it is worth noting that increased financial development

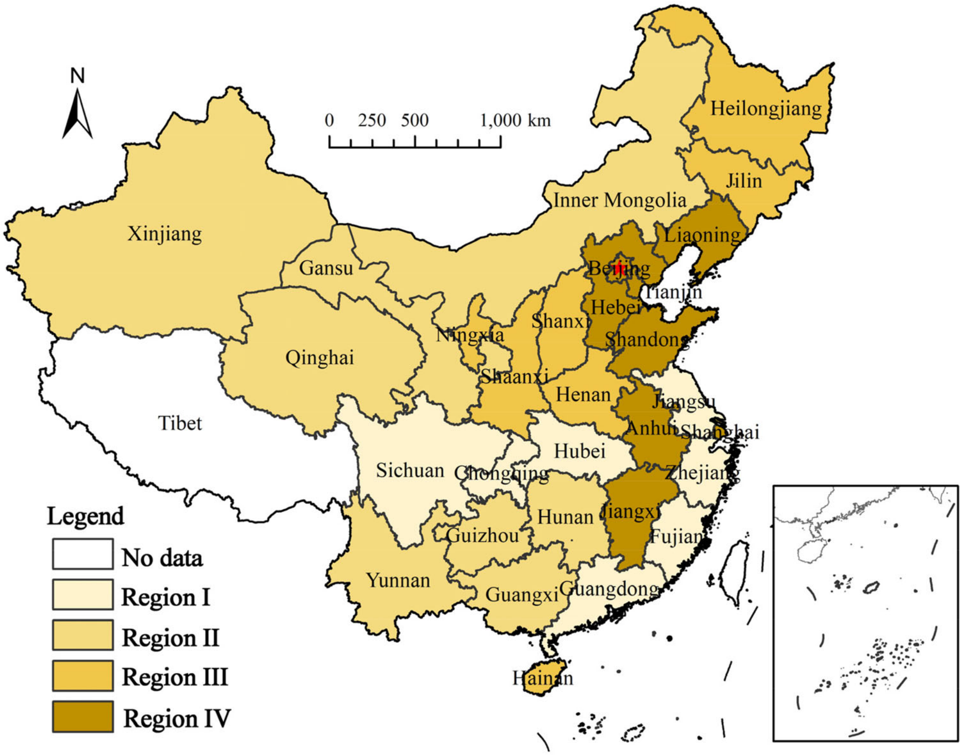

Figure 4. Regional division based on *GTR* and *GEN*.
Source: Self-Calculated.

Table 5. Results of the regional heterogeneous analysis.

Variable	(1) Region I	(2) Region II	(3) Region III	(4) Region IV
LnGTR	0.152***	0.0637***	0.0584	0.0193
	(3.26)	(2.87)	(1.23)	(0.46)
LnGEN	0.0870	0.0817**	0.119***	0.0267**
	(1.55)	(2.21)	(3.72)	(2.61)
LnFD	0.564***	0.225***	0.650***	0.671***
	(8.53)	(3.64)	(9.85)	(10.21)
LnUR	0.301	2.716***	0.691*	−0.551*
	(0.90)	(7.63)	(1.75)	(-1.92)
LnES	0.110	0.247	−0.293	−0.189***
	(0.67)	(1.62)	(-1.56)	(−2.89)
LnISU	0.116	−0.494***	−0.688***	−0.295***
	(0.86)	(−4.88)	(−6.60)	(−2.88)
_Cons	9.044***	13.64***	8.967***	8.920***
	(16.43)	(20.63)	(13.29)	(21.45)
R^2	0.9353	0.4759	0.8148	0.8439

Notes: Asterisks indicate significance at the 0.01 ***, 0.05 **, and 0.1 * levels.
Source: Self-Calculated.

in all four regions has a positive influence on local green growth, especially in regions with a lower level of green energy development (i.e., Regions III & IV). This may be due to improved financial markets favouring the financing capacity of emerging, environmentally friendly companies. Furthermore, the urbanisation rate has a negative impact on *GGR* in Region IV (e.g., Hebei and Shandong), which indicates that the improved urbanisation rate is not conducive to *GGR* in regions with relatively high green trade and low green energy. These results further show that the sufficient development of green energy is the key to regional green growth.

5.4. Discussions

Based on the benchmark regression results, it is emphasised that green trade refers to trade in technologies and products that are environment-friendly and resource-saving in the process of production and utilisation. Therefore, the growth of green trade is conducive to fewer emissions and less consumption of resources, which results in green economic growth. The positive nexus between green trade and green growth in this study is consistent with the findings of Talebzadehhosseini and Garibay (2022), who conclude that the increase of green products contributes to the overall green growth performance of the country. The results in this study also indicate that increased green energy development can significantly promote China's green growth, which can promote macroeconomic growth, the green transition of energy consumption structure, and considerable environmental synergy benefits. Similar conclusions can be found in Sohag et al. (2019) and Dai et al. (2016). Furthermore, the positive nexus between financial development in this study shows that the improvement in financial development benefits the financing environment for emerging enterprises. To be more specific, financial constraints serve as a major barrier to some companies and citizens using cleaner energy, and thus is not conducive to regional green economic development among such citizens (Baulch et al., 2018). Besides, this study concludes that energy consumption structure dominated by coal will exacerbate pollution emissions and the greenhouse effect in China, thereby hindering green growth.

As for the estimation results of heterogeneous analysis, one can see that *MGT* and *HGT* can accelerate green growth in China, and the impacts of *GTR* and *GEN* on *GGR* are heterogeneous in regions with different levels of green trade and green energy. Higher technological green products have also been shown to be more energy efficient and emit fewer emissions than traditional products. As can be seen from Figures 2 and 3, China's green trade and green energy have achieved unprecedented performance in recent years, especially in the southeastern coastal regions. However, the level of development of green trade and green energy in northwest China is relatively lower due to the uneven regional distribution of technological levels and financing levels in the country. This situation not only hinders the improvement of the economy's green and sustainable development, but also restricts the coordinated development of the 3Gs (i.e., green growth, green trade, and green energy) in China. According to the existing literature, environmental regulation plays a significant role in promoting the development of green energy, improving green product innovation, and accelerating green growth (Song et al., 2020; Wang & Shao, 2019; Zhao et al., 2022).

6. Further discussion

6.1. Asymmetric analysis

This paper employs the quantile regression approach to further explore the asymmetric characteristics of the impact of *GTR* and *GEN* on *GGR* in China. The results of which are reported in Table 6 and Figure 5.

Table 6. Results of the quantile regression.

	Quantiles				
Variables	10th	25th	50th	75th	90th
LnGTR	−0.046	0.136***	0.120***	0.043*	0.074*
	(−0.55)	(4.21)	(4.10)	(1.79)	(1.73)
LnGEN	−0.102**	0.014	−0.017	−0.020	0.035**
	(−2.32)	(0.61)	(−1.04)	(−1.62)	(2.00)
LnFD	1.426***	0.843***	0.823***	0.872***	0.774***
	(6.35)	(9.79)	(20.56)	(24.04)	(12.88)
LnUR	−1.946***	−1.099***	−1.079***	−0.932***	−1.018***
	(−3.88)	(−3.95)	(−5.01)	(−6.50)	(−4.41)
LnES	−0.465**	−0.173	−0.078	−0.075*	0.013
	(−2.27)	(−1.07)	(−0.64)	(−1.80)	(0.17)
LnISU	−0.930***	−0.473***	−0.400***	−0.509***	−0.306***
	(−4.19)	(−3.41)	(−3.58)	(−7.49)	(−2.96)
_Cons	3.170**	6.264***	6.862***	7.412***	7.796***
	(2.56)	(11.21)	(19.80)	(48.28)	(25.11)
R-squared	0.8670	0.8641	0.8596	0.8667	0.8612

Notes: Asterisks indicate significance at the 0.01 ***, 0.05 **, and 0.1 * levels.
Source: Self-Calculated.

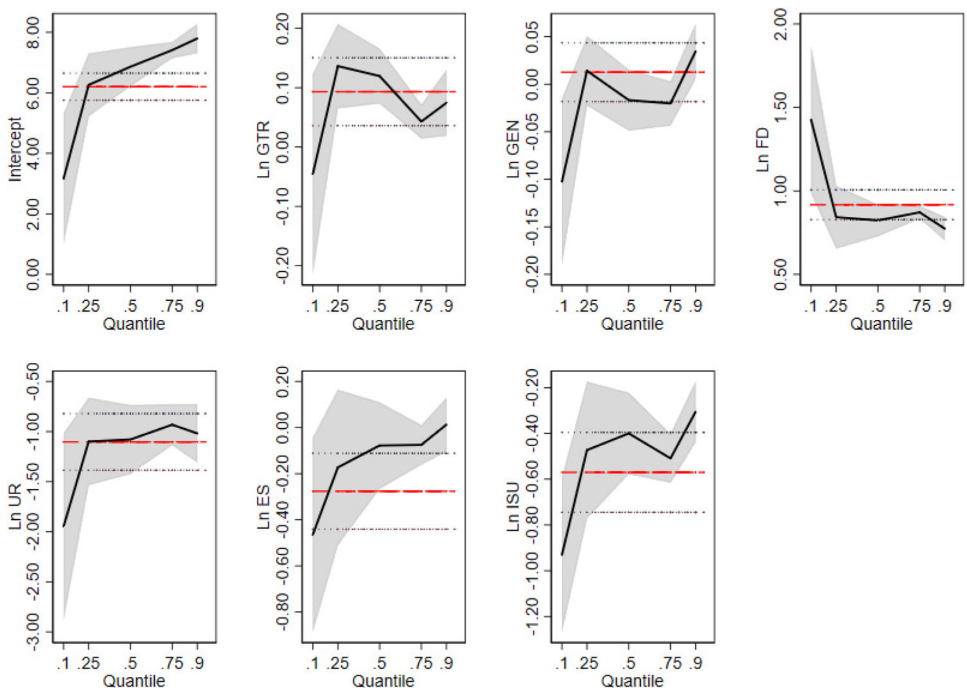

Figure 5. Coefficients of quantile regression.
Notes: The conditional quantiles of *GGR* is shown in the *x*-axis; various variables are shown by the *y*-axis.
Source: Self-Calculated.

From Table 6 and Figure 5, one can see that the impacts of financial development, urbanisation rate, and industrial structure upgrading on green growth are consistent, while green trade, green energy, and energy structure affect green growth asymmetrically. Specifically, at the 10th quantile, *GTR* has no significant impact on *GGR*. The positive influence of *GEN* on *GGR* exists at the 90th quantile. In terms of the control variables, the influence of *FD* on *GGR* is statistically significant both in the regions with high and low green growth, which reflects the universality of financial development. It is also worth noting that the positive influence of *FD* on *GGR* is greatest in regions with low levels of green growth, which also indicates that the financial development of these regions needs to be improved. Besides, the significant influence of energy structure on green growth exists only at the 10th and 75th quantiles, and the elastic coefficient at the 10th quantile is much higher than that at the 75th quantile. There is an urgent need to promote energy transition in regions with low green growth, such as Qinghai, Gansu, and Ningxia. In addition, regions with low green growth are not suitable for vigorously developing green trade and the green energy industry, but can focus on improving the level of financial development and upgrading the energy structure, thereby improving local green growth. The main possible reason is that local green growth may be restricted by the relatively backward level of economic development and financing environment and energy consumption habits, and the fact that equipment cannot be easily changed. As the financial environment improves, residents and enterprises are able to replace equipment such as coal-fired boilers with green energy.

6.2. Mediating mechanism

6.2.1. Approach

The impact of *GEN* on *GGR* is relatively intuitive, while the indirect influence of *GTR* on *GGR* is worth discussing. Furthermore, this paper uses a mediation analysis approach based on SYS-GMM to empirically investigate the mediation impact mechanism between *GTR* and *GGR*. Following the literature review in Section 2.2, this paper proposes the indirect impact of *GTR* on *GGR* mainly through the following three effects: the investment effect (Jones & Manuelli, 1990), labour effect (Grossman & Helpman, 1991; Young, 1991), and technical effect (Grossman & Helpman, 1991). The identifying assumption functions are defined as follows:

$$LnGGR_{i,t} = \alpha_0 + \alpha_1 LnGGR_{i,t-1} + \alpha_2 LnGTR_{i,t} + \alpha_3 LnGEN_{i,t} + \sum_{k=1}^{4} \beta_k LnX_{k,i,t} + \delta_{i,t} \tag{9}$$

$$LnM_{i,t} = \varphi_0 + \varphi_1 LnM_{i,t-1} + \varphi_2 LnGTR_{i,t} + \varphi_3 LnGEN_{i,t} + \sum_{k=1}^{4} \beta_k LnX_{k,i,t} + \mu_{i,t} \tag{10}$$

$$LnGGR_{i,t} = \gamma_0 + \gamma_1 LnGGR_{i,t-1} + \gamma_2 LnGTR_{i,t} + \gamma_3 LnGEN_{i,t} + \gamma_4 LnM_{i,t} + \sum_{k=1}^{4} \beta_k LnX_{k,i,t} + \varepsilon_{i,t} \tag{11}$$

$$MER = \left| \frac{\varphi_2 \cdot \gamma_4}{\alpha_2} \right| \tag{12}$$

Table 7. Results of the mechanism analysis.

Variable	(1) *LnGGR*	(2) *LnINE*	(3) *LnLAE*	(4) *LnTEE*	(5) *LnGGR*
$LnGGR_{i,t-1}$	0.759***				0.459***
	(58.48)				(16.65)
$LnINE_{i,t-1}$		0.814***			
		(17.26)			
$LnLAE_{i,t-1}$			0.876***		
			(69.01)		
$LnTEE_{i,t-1}$				0.678***	
				(20.84)	
LnGTR	0.0569***	0.0115*	0.0148***	0.0873***	0.0317***
	(12.56)	(1.71)	(3.15)	(6.00)	(5.40)
LnGEN	0.0190***	0.0067	0.00563	−0.0107	0.0243***
	(4.59)	(1.36)	(1.17)	(−1.02)	(3.35)
LnINE					0.115***
					(8.95)
LnLAE					0.199***
					(6.60)
LnTEE					0.0346***
					(3.66)
LnFD	0.0845***	0.159***	0.00754	0.248***	0.256***
	(5.02)	(3.58)	(0.86)	(5.05)	(11.87)
LnUR	0.206***	−0.251	0.0209	−0.0931	−0.451***
	(3.55)	(−1.29)	(0.23)	(−0.39)	(−3.70)
LnES	−0.280***	−0.201***	0.0937***	−0.360***	−0.125***
	(−6.66)	(−8.51)	(3.45)	(−4.37)	(−3.43)
LnISU	−0.301***	−0.0111	0.00527	−0.206**	−0.396***
	(−14.90)	(−0.30)	(0.34)	(−2.52)	(−12.83)
_Cons	2.335***	0.538***	0.213	0.609*	3.273***
	(32.41)	(2.91)	(1.56)	(1.82)	(13.02)
AR(1)	0.0571	0.0456	0.0001	0.0028	0.0693
AR(2)	0.7552	0.4724	0.1325	0.6912	0.7054
Sargan	0.9420	0.9860	0.9574	0.9475	0.9535

Notes: Asterisks indicate significance at the 0.01 ***, 0.05 **, and 0.1 * levels.
Source: Self-Calculated.

where *GGR* denotes green growth, *GTR* is green trade, *GEN* represents green energy, *X* is the control variables (i.e., *FD*, *UR*, *ES*, and *ISU*). M denotes the mediating variables, including investment effect (*INE*), measured by the registered capital of foreign-invested enterprises, labour effect (*LAE*), measured by the number of undergraduate graduates in institutions of higher learning, and technical effect (*TEE*), measured by the number of local patents granted. α_2 denotes the total effects (Baron and Kenny, 1986), α_5 is the direct effect of *GTR* on *GGR*, and $\varphi_2 \cdot \gamma_4$ denotes the indirect effect (mediation effect) of each mediator (i.e., *M*) if φ_2 and γ_4 are statistically significant. Furthermore, *MER* is the mediation effect ratio.

6.2.2. Results of mediating analysis

The regression results based on Eqs. (9) – (11) are shown in Table 7. This table can serve as a basis for drawing several conclusions.

First, one can see from Columns (2) – (4) that the estimated elastics of *GTR* on *INE*, *LAE*, and *TEE* are all positive and statistically significant, which shows that increased green trade can significantly promote investment, labour capital, and technology development. A 1% increase in the *GTR* can improve foreign investment by 0.0115%, improve highly educated labour capital by 0.0148%, and improve

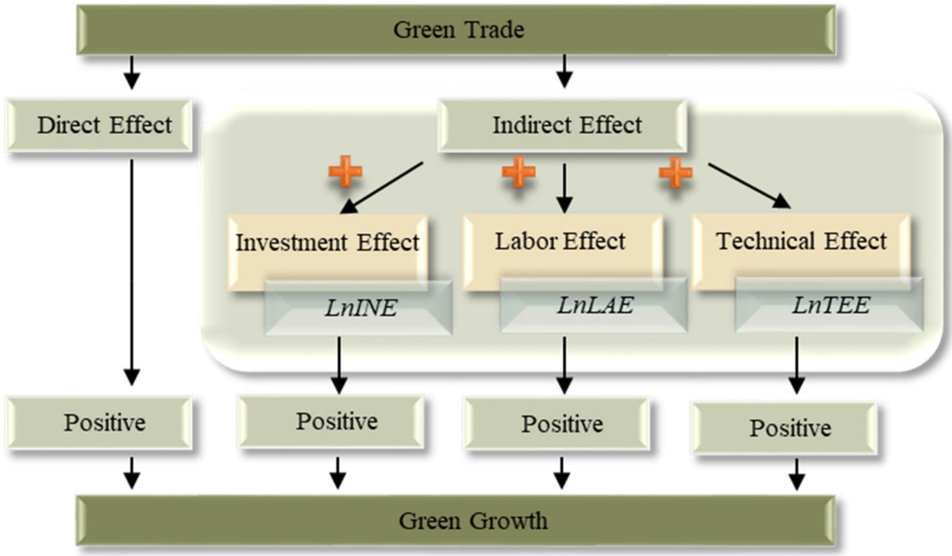

Figure 6. Mediating mechanism of *GTR* on *GGR*.
Source: Self-Calculated.

technological development by 0.0873%. Second, Column (5) shows that the results of *INE*, *LAE*, and *TEE* on *GGR* are all positive (i.e., 0.115, 0.199, and 0.0346, respectively). These results show that improving foreign investment, highly educated labour capital, and technology development are all effective methods for increasing green growth. Third, combining the estimation results with Eq. (12), the mediation effect ratios of *INE*, *LAE*, and *TEE* are 2.3%, 5.2%, and 5.3%, respectively. These results indicate that the investment effect, labour effect, and technical effect are all positive and effective mediators between green trade and green growth. To be more specific, the increased trade value of green products can improve green growth by increasing local foreign investment, highly educated labour capital, and technology development. This conclusion is consistent with the second hypothesis. According to the above mediation effect analysis, the specific mediation impact mechanism is shown in Figure 6.

7. Conclusions and policy implications

7.1. Conclusions

To empirically investigate the 3 G nexus in China, this paper measures provincial green growth by employing five types of indicators – economic growth, environmental pollution loss, carbon emissions loss, natural resource loss, and environmental and natural resource benefits. A balanced panel dataset covering 30 provinces in China is used for analysis. Furthermore, we discuss the heterogeneity of products and regions, asymmetry, and the mediation impact mechanism in the 3 G nexus. This paper reaches the following major conclusions:

(1) The benchmark regression results indicate that green trade and green energy can significantly accelerate green growth in China. Furthermore, the products'

heterogeneous analysis shows that increasing *MGT* and *HGT* can contribute to green growth. The regional heterogeneous analysis indicates that a significant positive impact exists between *GTR* and *GGR* in the regions with a high level of green energy development (i.e., Region I and II); and the positive impacts of green energy on green growth are statistically significant in Regions II, III, and IV. (2) Influences of green trade, green energy, and energy structure on green growth differ across quantiles, which shows the symmetricity; while the impacts of financial development, urbanisation rate, and industrial structure upgrading on green growth are consistent. (3) The mediating analysis indicates that the investment effect, labour effect, and technical effect are positive mediators of the nexus between *GTR* and *GGR*. Specifically, the increased trade value of green products can improve green growth by increasing foreign investment, highly educated labour capital, and technology development.

7.2. Policy implications and limitations

Following are the policy implications of this study. (1) China should increase its support for green trade and green energy development, thereby effectively achieving green growth. Improving financial development, increasing the urbanisation rate, and reducing coal's share of total energy consumption are also essential for the improvement of green growth and the achievement of sustainable development. (2) China needs to increase input in scientific and technological innovation, actively promote the implementation of green technology innovation achievements, thereby improving the production efficiency of products and raising the technological level in the trade products. Furthermore, to improve green economic growth, Chinese governments must develop differentiated policies according to conditions. For instance, provinces in Regions II, III, and IV can make full use of their advantages and vigorously develop the renewable energy industry, thereby enhancing the positive impacts of green energy on green growth. (3) Given that the positive investment effect, labour effect, and technology effect are the effective mediators between green trade and green growth, governments can accelerate the green economic growth in China through improving investment, talent introduction policy, and the technological innovation subsidy. For instance, efforts must be made to improve the local financial development and accelerate green energy transition by subsidising the replacement of energy-intensive household equipment with energy-efficient equipment. This will improve the financing level and energy consumption habits of households and small businesses, thus making them more conducive to achieving green growth.

The paper still has several shortcomings. First, the index of green trade is measured by the provincial trade value of green products in this study. In future research, the diversity of green products and the diversification of trade cooperation countries can be taken into account, and formulate a comprehensive index of green trade to comprehensively measure the relationship between green trade and green growth. Second, this study only employs three dimensions of investment, labour, and technical effects in exploring the internal mediation impact mechanism. A more in-depth analysis can be carried out by investigating the mediation mechanism of the impacts of green trade on green growth from more dimensions. More importantly, the spatial spill-over effects of green trade and green energy on green growth can be further investigated.

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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. List of abbreviations.

Abbreviations			
3G	Green growth, green trade, and green energy	GEN	Green energy
A-B	Arellano-Bond	GTR	Green trade
CCIED	China Customs Import and Export Database	HS	Harmonized System
CEAD	China Emission Accounts and Datasets	RE	Radom effects
CO_2	Carbon dioxide	SBM	Slacks-based measure
COP26	The 26th United Nations Climate Change Conference	SYS-GMM	System generalised method of moments
CSY	China Statistics Yearbook	USD	USA dollar
FE	Fixed effect		