

# Do Logistics Development and Tourism Development Contribute to Low-Carbon Economy? Empirical Evidence from Technological Innovation and Clean Energy Utilization in China

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## Abstract

With the intensification of the conflict between environmental deterioration and economic growth, low-carbon economy has attracted more and more attention from various industries. Using panel data of 30 provinces in China from 2000 to 2019, this paper adopts a fixed effect model and threshold effect model to study the non-linear threshold effects of logistics development and tourism development on low-carbon economy from the perspective of technological innovation and clean energy. The results show that, firstly, logistics development and tourism development have promoting effects on low-carbon economy; secondly, with the improvement of technological innovation and the increase in the use of clean energy, the promotion of logistics development and tourism development on low-carbon economy are gradually enhanced; finally, there is an obvious regional heterogeneity in the above threshold effects: Within the threshold range, the development of logistics and tourism in the eastern regions has a stronger promoting effect on the low-carbon

economy than in the central and western regions.

**Keywords:** Logistics development, Tourism development, Technological innovation, Clean energy, Low-carbon economy, Threshold effect

## 1. Introduction

In recent years, with the intensification of global climate problems and environmental degradation, achieving sustainable development has become a major challenge for all countries (Ma et al., 2021). The Chinese economy has achieved significant growth over the past few decades, while at the same time putting enormous pressure on environmental quality and natural resources (Chenghu et al., 2021). According to the World Bank, more than 30% of global carbon dioxide emissions came from China in 2021. As the largest developing country in the world, China has also begun to attach great importance to climate issues and has implemented a series of strategies, measures and actions to address climate change. In 2020, President Xi Jinping solemnly declared at the 75th United Nations General Assembly: China's carbon dioxide emissions will strive to peak before 2030 and achieve carbon neutrality before 2060.

China's emphasis on carbon emissions will lead to the inevitable trend of low-carbon economic development in the future. In this process, low-carbon and sustainable development of various industries will play an important role. Logistics industry is the foundation and leading industry of the national economy (Zhang et al., 2019). Against the background of carbon neutrality and carbon peak, low-carbon logistics is a new requirement for the development of the logistics industry and environmental protection, and it is of great significance to realize the coordinated development of the logistics industry and the ecological environment (Shi, 2018). As an important part of the gross domestic product, tourism directly and indirectly provides a significant proportion of jobs in the country (Jebli et al., 2019). Since the development of tourism usually requires a lot of infrastructure investment in transportation and services, and its rapid development accelerates energy consumption and environmental pollution, therefore, it is very important to promote the low-carbon development of tourism (Bi & Zeng, 2019).

Low-carbon development is closely related to energy structure transformation and technological innovation. On the one hand, increasing the use of clean energy will help reduce the dependence on fossil energy and promote energy conservation and emission reduction. On the other hand, green technology R&D and innovation can effectively reduce environmental pollution and help realize the transformation of the energy structure (Li et al., 2021). Therefore, how to promote the low-carbon development of logistics and tourism through technological innovation and clean energy is of great practical significance to the sustainable development of China's economy.

Based on the above analysis, this study uses panel data of 30 provinces in China from 2000 to 2019 to study the impacts of logistics development and tourism development on low-carbon economy, and further analyzes the threshold effects of technological innovation and clean energy in the above impact processes. This study differs from others in the following aspects: firstly, the fixed effect model is used to study the impacts of logistics development and tourism development on the low-carbon economy; secondly, the panel threshold regression model is used to study the nonlinear threshold effects of technological innovation and clean energy in the above impact processes; finally, due to significant differences in the industrial

structure, resource endowment, and technological level of different regions in China, the characteristics of regional heterogeneity are considered when studying the above threshold effects, and also the corresponding sustainable development strategies were proposed.

The main contributions of this study are as follows: On the one hand, this study enriches the existing literature, and expounds the relationship among logistics development, tourism development, technological innovation, clean energy and low-carbon economy from a theoretical perspective; on the other hand, it has rather practical significance to promote the low-carbon development of China's logistics and tourism, and to further explore how to achieve sustainable economic growth in China on this basis; in addition, this study also provides ideas for solving the unbalanced development of low-carbon economy among different regions in China.

The rest of the paper is structured as follows: Section 2 is a literature review; section 3 analyzes the threshold mechanism and puts forward relevant hypotheses; section 4 builds the model and gives necessary explanations for the variables and data; section 5 is the empirical research results and analysis; section 6 is the robustness test; section 7 is the main conclusions and suggestions.

## **2. Literature Review**

In recent years, the greenhouse effect is intensifying due to the increase in global carbon dioxide emissions. Logistics and tourism, as important pillar industries for economic growth, have received extensive attention because of the large amount of carbon emissions caused by them. Guo et al. (2022) analyzed the relationship between the logistics industry and carbon emissions, and found that population, energy and property in the logistics industry have a greater impact on carbon emissions. Xia et al. (2022) proposed that there is inequality in the carbon intensity of China's transportation industry between eastern and western regions, and the gap in production technology is the determinant of inequality. Bi and Zeng (2019) used a spatial economic model to find a significant inverted U-shaped relationship between tourism development and carbon emissions. Zikirya et al. (2021) believed that there is a long-term equilibrium relationship between China's carbon dioxide emissions, air pollution and tourism flows. Zhang et al. (2019) selected data from Thailand from 2001 to 2017 and found that logistics and transportation-related infrastructure are significantly positively correlated with inbound tourism, while carbon emissions and fossil fuels are significantly negatively correlated with inbound tourism. Wang et al. (2021) found that there is a two-way causal relationship between China's domestic tourism revenue, carbon emissions and economic growth through the Granger causality test, and the carbon emissions of the transportation industry determine the trend of the total carbon emissions of the domestic tourism industry.

While the development of logistics and tourism has caused carbon emissions and environmental pollution problems, it has an important contribution to economic growth. At present, many scholars have studied the relationship between logistics, tourism and economic growth. Saidi et al. (2020) conducted research on developing countries and confirmed that the development of transport and logistics infrastructure is conducive to sustainable economic growth. Considering the logistics sector's significant contributions to economic development,

Muslija et al. (2021) proposed that it is necessary to stimulate the development of the logistics sector based on renewable energy according to a study on the seven largest developed economies in the world. Taking the BRICS, Saudi Arabia and Italy as the research objects, empirical results of Rasool et al. (2021), Naseem (2021) and Siano and Canale (2022) all verified the promotion of tourism on economic growth. The research results of Zhang and Gao (2016) showed that the development of sustainable tourism is conducive to improve local environmental quality and promote regional economic growth. In addition, studies have shown that the low-carbon development of logistics and tourism will also affect economic growth. A study by Raihan and TuspekovaA (2022) in Malaysia showed that economic growth and sustainable low-carbon development can complement each other, and a series of low-carbon measures can create new employment opportunities, and promote economic growth and carbon emission reduction. Weng (2022) found that the coordination between the development of the logistics industry and the low-carbon level of the economy is increasing, and the mutual promotion between the two is becoming increasingly evident; Mohsin et al. (2022) believed that countries along the “Belt and Road” can achieve economic growth and environmentally sustainable development by developing green logistics. Zhang (2022) believed that from the perspective of the world, especially the developing countries, high-quality tourism development is conducive to achieving the double dividends of economic growth and low-carbon transformation. Similarly, the research results of Yang et al. (2021) showed that the development of tourism is conducive to a balance between economic growth and emission reduction in the national economy.

As a stimulator of productivity improvement and economic growth, and a trigger of the transformation of energy structure, technological innovation is considered to be a key role in the low-carbon development of logistics and tourism. Ma et al. (2021) found that higher technological innovation, R&D expenditure and renewable energy use can reduce carbon dioxide emissions, thereby promoting the development of China’s low-carbon economy. Guo et al. (2021) and Zhu et al. (2021) conducted research on the provinces along the Belt and Road in China and 30 provinces in China, respectively, showed that technological innovation can improve the environmental efficiency of the logistics industry. Godil et al. (2021) used the QARDL method to find that technological innovation has a negative impact on carbon emissions in China’s transportation sector. With the aid of Augmented Mean Group (AMG) estimator, Chenghu et al. (2021) found that tourism development increases carbon emissions, while technological innovation reduces carbon emissions. Razzaq et al. (2020) proposed that tourism development and technological innovation can significantly reduce carbon dioxide emissions in the long run, and suggested that the Chinese government should implement a comprehensive “tourism technology” policy based on the asymmetric emission reduction effects of tourism and technological innovation.

The development and application of clean energy is one of the effective ways to promote alleviate environmental pollution and promote the development of low-carbon economy, and thus, it will also play an important role in the low-carbon development of economy, logistics and tourism. A Research by Zeqiraj et al. (2020) in EU Member States showed that clean energy consumption and production are conducive to the realization of low-carbon economy.

Islam et al. (2022) believed that clean energy has a significant positive impact on the sustainable development of ASEAN countries. Khan et al. (2020) showed that the use of renewable energy in logistics operations can improve environmental and economic performance by using structural equation models. Surya et al. (2021) suggested that the use of clean energy in cities can reduce the environmental pollution from transportation. Aydin (2022) argued that renewable energy consumption has a positive impact on tourism development according to a research on Turkey. The empirical results of Jebli et al. (2019) on Central and South American countries showed that the use of renewable energy and the development of green tourism are of great significance to the economy and environment of the region.

To sum up, although previous scholars have conducted many studies on the links among logistics development, tourism development, carbon emissions and economic growth, there is still no clear conclusion on the impacts of logistics development and tourism development on the low-carbon economy; in addition, there is also no research on the possible moderating roles and threshold effects of technological innovation and clean energy in the above impact processes.

Therefore, using the panel data of 30 provinces in China from 2000 to 2019, this paper firstly studies the impacts of logistics development and tourism development on low-carbon economy; secondly, technological innovation and clean energy are selected as threshold variables to further analyze their moderating roles and threshold effects in the above-mentioned processes; finally, the regional heterogeneity of the samples is analyzed, and corresponding countermeasures and suggestions are put forward.

### **3. Threshold Effect Mechanism and Hypotheses**

Based on the above literature review, this paper first puts forward the following hypothesis (H1) about the impact mechanism of logistics development and tourism development on low-carbon economy; next, the possible threshold effects of technological innovation and clean energy in the above-mentioned impact processes are analyzed, and other corresponding hypotheses are also put forward.

H1: Logistics development and tourism development can promote low-carbon economy.

Technological innovation includes introducing new production methods, producing new products or improving product quality, and developing new markets, new forms of market organization, and a new supply of raw materials (Schumpeter, 2021). According to the endogenous growth theory, technological innovation is the determinant factor to ensure sustained economic growth, and characterized by return on scale, it can increase productivity and achieve higher economic growth (Sokolov-Mladenović et al., 2016). That is to say, because of the high initial costs, the impact of technological innovation on economic growth may not be obvious at the initial stage; with the wide application of innovation achievements, the return on scale and economic benefits generated by technological innovation will continue to increase (Acheampong et al., 2022). In addition, green investment and technological innovation are also seen as effective factors to reduce carbon dioxide emissions



(Luo et al., 2021), and their development helps to improve clean production and energy efficiency, thereby optimizing the industrial structure and driving low-carbon economic growth (Ding & Liu, 2022).

Based on the above analysis, it can be inferred that the impact of technological innovation on low-carbon economy might have threshold characteristics. Acheampong et al. (2022) found that technological innovation has a U-shaped relationship with economic growth, i.e., economic growth declines in the early stages of technological innovation, but after technological innovation reaches a certain threshold, economic growth increases significantly. Li and Wei (2021) also proposed that there is a nonlinear relationship between technological innovation and economic growth, i.e., with the increase of carbon emissions, the positive effect of technological innovation on economic growth is weakened.

Therefore, technological innovation is selected here as one threshold variable to study its threshold effects in the impacts of logistics development and tourism development on low-carbon economy, and proposes the following hypotheses 2, 3 and 4.

H2: Technological innovation has a positive impact on the development of logistics and tourism.

H3: The logistics development has a nonlinear threshold impact on the low-carbon economy. As the level of technological innovation moves from a low threshold to a high threshold, the promotion of logistics development on low-carbon economy is gradually enhanced.

H4: The tourism development has a non-linear threshold impact on the low-carbon economy. As the level of technological innovation moves from a low threshold to a high threshold, the promotion of tourism development on low-carbon economy is gradually enhanced.

Clean energy refers to non-fossil energy including solar energy, hydro energy, wind energy, geothermal energy and biomass energy, etc. It is of great significance to reduce environmental pollution, adjust energy structure and achieve sustainable development (Islam et al., 2022). In recent years, the issue of economic losses caused by climate change, environmental damage and fossil fuel consumption has attracted worldwide attention, thus the transformation of the energy structure and the increased use of clean energy have become important energy strategies in various countries (Qi & Li, 2017). The clean energy industry is a capital-intensive industry, and its initial development requires a large amount of investment, R&D of energy technology and government policy support, therefore, compared with the traditional fossil energy industry, in the early stage of the development of the clean energy industry, its start-up and operation costs are higher and the economic benefits are lower (Wang et al., 2021) ; however, with the development of the clean energy industry, its scale effect, agglomeration effect and environmental protection effect will gradually appear, and its economic benefits will also increase (Tu et al., 2020).

Based on this, it can also be inferred that the impact of clean energy on low-carbon economy might have threshold characteristics. High clean energy consumption can effectively promote the low-carbon development of the economy. Chen et al. (2020) constructed a threshold model and considered that only when a country's clean energy consumption exceeds a certain

threshold, its impact on economic growth is positive and significant. Li et al. (2021) also found that only when clean energy consumption reaches a higher level, can it have a positive effect on low-carbon economy.

Therefore, clean energy is assumed as a threshold variable to study its threshold impact on the impact of logistics and tourism development on the low-carbon economy. The following assumptions 5, 6, and 7 are proposed.

H5: Clean energy has a positive impact on the development of logistics and tourism.

H6: The logistics development has a nonlinear threshold impact on low-carbon economy. As the use of clean energy moves from a low threshold to a high threshold, the promotion of logistics development on low-carbon economy is gradually enhanced.

H7: The tourism development has a nonlinear threshold impact on low-carbon economy. As the use of clean energy moves from a low threshold to a high threshold, the promotion of tourism development on low-carbon economy is gradually enhanced.

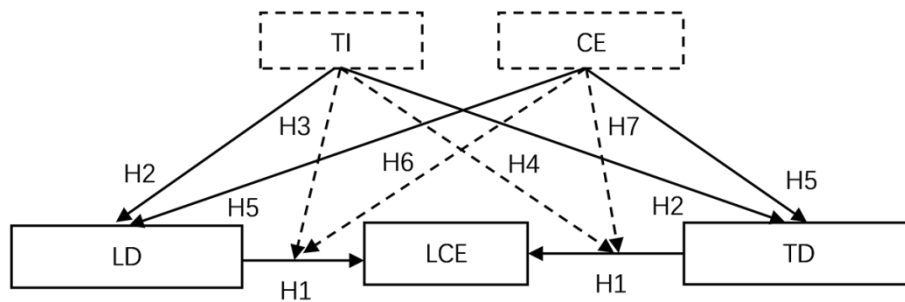


Figure 1. Influence mechanism framework

The specific influence mechanism framework is shown in Figure 1, in which the dotted arrow represents the possible threshold effects, and the dashed box represents the threshold variables. Here: TI denotes technological innovation; CE denotes clean energy; LD denotes logistics development; TD denotes tourism development; LCE denotes low-carbon economy.

#### 4. Model Specification and Data Description

##### 4.1 Econometric Model

In order to verify the promotion effects of logistics development and tourism development on low-carbon economy (H1), and the positive impacts of technological innovation and clean energy on development of logistics and tourism (H2 and H5), the following models are constructed:

$$LCE_{it} = \delta_0 + \delta_1 LD_{it} + \delta_2 Control_{it} + \varepsilon_{it} \tag{1}$$

$$LCE_{it} = \kappa_0 + \kappa_1 TD_{it} + \kappa_2 Control_{it} + \varepsilon_{it} \tag{2}$$



$$LD_{it} = \alpha_0 + \alpha_1 TI_{it} + \alpha_2 CE_{it} + \alpha_3 Control_{it} + \varepsilon_{it} \quad (3)$$

$$TD_{it} = \beta_0 + \beta_1 TI_{it} + \beta_2 CE_{it} + \beta_3 Control_{it} + \varepsilon_{it} \quad (4)$$

Here,  $LCE_{it}$  is the low-carbon economy of province in  $i$  period  $t$ ,  $LD_{it}$  is the logistics development in province  $i$  in the period  $t$ ,  $TD_{it}$  is the tourism development in province  $i$  in the period  $t$ ,  $CE_{it}$  is the use of clean energy,  $TI_{it}$  is technological innovation,  $Control_{it}$  represents a series of control variables that may affect the results, including: urbanization level (URB), and social investment level (INVE),  $\varepsilon_{it}$  is a random error term.

In order to analyze the impacts of technological innovation and clean energy on low-carbon economy, and their possible moderating roles in the processes of logistics development and tourism development promoting low-carbon economy, the following models are constructed:

$$LCE_{it} = \eta_0 + \eta_1 LD_{it} + \eta_2 TI_{it} + \eta_3 LD_{it} * TI_{it} + \eta_4 Control_{it} + \varepsilon_{it} \quad (5)$$

$$LCE_{it} = \mu_0 + \mu_1 LD_{it} + \mu_2 CE_{it} + \mu_3 LD_{it} * CE_{it} + \mu_4 Control_{it} + \varepsilon_{it} \quad (6)$$

$$LCE_{it} = \omega_0 + \omega_1 TD_{it} + \omega_2 TI_{it} + \omega_3 TD_{it} * TI_{it} + \omega_4 Control_{it} + \varepsilon_{it} \quad (7)$$

$$LCE_{it} = \rho_0 + \rho_1 TD_{it} + \rho_2 CE_{it} + \rho_3 TD_{it} * CE_{it} + \rho_4 Control_{it} + \varepsilon_{it} \quad (8)$$

In this model, the positive and negative of the interaction coefficients  $\eta_3$ ,  $\mu_3$ ,  $\omega_3$  and  $\rho_3$  indicate the directions of the moderating roles played by technological innovation and clean energy in the processes of logistics development and tourism development promoting low-carbon economy.

In order to accurately identify the factors that affect the promotion effects of logistics development and tourism development on low-carbon economy, and verify the existence of the non-linear relationship and the threshold effects of technological innovation (H3 and H4), this paper uses the panel threshold regression model proposed by Hansen (1999). The single threshold regression models can be expressed as:

$$LCE_{it} = \theta_0 + \theta_1 LD_{it} * I(TI_{it} \leq \gamma) + \theta_2 (TI_{it} > \gamma) + \theta_3 Control_{it} + \varepsilon_{it} \quad (9)$$

$$LCE_{it} = \phi_0 + \phi_1 TD_{it} * I(TI_{it} \leq \gamma) + \phi_2 (TI_{it} > \gamma) + \phi_3 Control_{it} + \varepsilon_{it} \quad (10)$$

Here,  $TI_{it}$  is the threshold variable,  $\gamma$  is the threshold value,  $LD_{it}$  and  $TD_{it}$  are the core explanatory variables affected by the threshold variable, and  $I(\cdot)$  is the indicator function. When the conditions in the corresponding brackets are satisfied, the value is 1, otherwise it is 0.

Similarly, in order to verify the threshold effects (H6 and H7) of clean energy in the processes of promoting low-carbon economy by logistics development and tourism development, the

following panel threshold regression models are constructed. The single threshold regression models can be expressed as:

$$LCE_{it} = \zeta_0 + \zeta_1 LD_{it} * I(CE_{it} \leq \gamma) + \zeta_2 (CE_{it} > \gamma) + \zeta_3 Control_{it} + \varepsilon_{it} \quad (11)$$

$$LCE_{it} = \psi_0 + \psi_1 TD_{it} * I(CE_{it} \leq \gamma) + \psi_2 (CE_{it} > \gamma) + \psi_3 Control_{it} + \varepsilon_{it} \quad (12)$$

The software used in the empirical study is Stata 16. In practice, there may exist multiple thresholds. The double threshold and multiple threshold models are expanded on the basis of equations (9), (10), (11) and (12), and thus not expounded here.

## 4.2 Variable Description

### 4.2.1 Explained Variables

Low carbon economy is an economic growth model characterized by reducing high carbon energy consumption and carbon emissions (DAI & Zhang, 2021). Refers to the research conducted by Zhou et al. (2017), Niu et al. (2022), and Dai and Zhang (2021), This paper uses the GDP carbon emission indicator, that is, the ratio of actual GDP to carbon emissions, to measure the development of low-carbon economies in various regions.

### 4.2.2 Core Explanatory Variables

#### (1) Logistics Development (LD)

According to the “China Tertiary Industry Statistical Yearbook”, logistics includes transportation logistics, warehousing logistics, trade logistics, distribution processing and packaging logistics, and postal logistics. As there is no division of the logistics industry in the China national economic industry classification catalogue, the existing statistical data lack categories for the total production value and energy consumption of logistics industry, while the output value of the “transportation, storage and postal industry” in the logistics industry accounts for more than 83%, which can reflect the development status and trend of the logistics industry to a large extent (Han et al., 2022). Considering the availability of data and referring to the research of most scholars on the logistics industry (Shi, 2018; Zhang et al., 2021), this paper uses the relevant statistical data of “transportation, storage and postal industry” to represent the development of the logistics industry.

#### (2) Tourism Development (TD)

Tourism is a comprehensive industry that provides products and services for tourists to carry out tourism activities. Referring to the research conducted by Destek et al. (2022) and Li et al. (2019), this paper uses the total tourism income of each province (including domestic tourism income and foreign exchange tourism income) to measure the development of regional tourism.

### 4.2.3 Threshold Variables

#### (1) Technological Innovation (TI)

The amount of invention patent authorization, as the key indicator to measure the level of technological innovation, reflects the level of regional technological innovation to a certain extent, and according to Godil et al. (2021) and Niu et al. (2022), this paper adopts the amount of invention patent authorization as an indicator to measure the level of technological innovation in each province.

## (2) Clean Energy (CE)

Clean energy refers to non-fossil energy including solar energy, hydro energy, wind energy, geothermal energy and biomass energy, and according to Wang et al. (2021), this paper selects the total power generation of renewable energy (including hydropower, solar energy, wind power and nuclear energy) to measure the use of clean energy in various provinces.

### 4.2.4 Control Variables

#### (1) The Level of Urbanization (URB)

The level of urbanization reflects the regional population and economic agglomeration and the quality of urban development to some extent, which has impacts on the development of logistics and tourism. According to Lin and Li (2022), this paper selects the proportion of the urban population to the total population to measure the urbanization level of each province.

#### (2) The Level of Social Investment (INVE)

The level of social investment is an important factor affecting economic development, which can have profound impacts on logistics and tourism through transportation infrastructure construction, tourism resource development, and R&D investment. According to Tu and Zhang (2020), this paper selects the total social investment in fixed assets to measure the level of social investment in each province.

Table 1. Variables descriptive statistics

Variable	Observations	Mean	Std. Dev	Minimum	Maximum
LCE	600	13.0452	0.7528	11.2262	15.6042
LD	600	24.605	1.0214	21.3751	26.6193
TD	600	16.0447	1.5345	11.4591	18.8338
TI	600	8.9156	1.7310	4.2485	13.1757
CE	600	4.6011	1.8327	0	8.1363
URB	600	3.8908	0.3051	2.9755	4.4954
INVE	600	8.5380	1.2978	5.0409	10.9813

Table 1 shows the descriptive statistics of the above variables.

### 4.3 Econometric Model

In order to study the impacts of logistics development and tourism development on low-carbon economy, and analyze the threshold effects of technological innovation and clean

energy in their impact processes, considering the availability of data, this paper selects provincial panel data of 30 provinces in China (except Tibet, Hong Kong, Macao and Taiwan) from 2000 to 2019 as the research sample. Here, the per capita GDP, patent authorization, logistics and tourism data are all from the China Statistical Yearbook, the statistical yearbooks and Statistical Bulletins of various provinces; the data on total power generation of renewable energy comes from the China Power statistics yearbook; the carbon dioxide emission data in each province over the years are from CEADs-China carbon accounting database. Before the empirical regression, in order to ensure the stability of the data, all the data was processed by natural logarithm and the variables were tested by unit root test and collinearity test. The results show that all the variables are stable at the first-order difference level and the VIF value is less than 10. Therefore, all the variables are stable and there is no multiple collinearity problem.

Table 2. Variables measurement and data sources

Variables	Symbol	Measurement	Data Sources
Low-carbon economy	LCE	GDP /carbon emissions	China Statistical Yearbook, CEADs—China carbon accounting database
logistics Development	LD	total production value of the logistics	Statistical yearbook of each province over the years
Tourism Development	TD	total tourism revenue	Statistical yearbook of each province over the years
Technological Innovation	TI	authorized amount of invention patents	China Statistical Yearbook
Clean Energy	CE	generation capacity of renewable energy	China Power Statistics Yearbook
The Level of Urbanization	URB	urban population/ total population	China Statistical Yearbook
The Level of Social Investment	INVE	total investment in social fixed assets	China Statistical Yearbook

Table 2 shows the summary of variables measurement and data sources.

## 5. Empirical Analysis

### 5.1 Fixed Effects Regression

In order to verify hypothesis 1, 2 and 5, and analyze the relationship among development of logistics and tourism, technological innovation, clean energy and low-carbon economy, this paper uses panel fixed effect regression for estimation.

Table 3. Fixed effect regression results 1

LCE	Model (1)	Model (2)	Model (5)	Model (6)	Model (7)	Model (8)
LD	0.302***		0.401***	0.231**		
TD		0.311***			0.480***	0.328***
TI			0.911***		0.802***	
CE				0.0237*		0.0889***
LD*TI			0.0815***			
LD*CE				0.134***		
TD*TI					0.0545***	
TD*CE						0.199***
URB	-0.228	-0.615**	-0.550***	-0.0168	-0.686***	-0.371*
INVE	0.138***	0.0384	-0.001	0.124**	0.023	-0.0128
_cons	5.316***	10.12***	24.97***	5.867***	25.94***	8.930***
N	600	600	600	600	600	600
R <sup>2</sup>	0.9610	0.9613	0.9658	0.9649	0.9658	0.9648

Table 4. Fixed effect regression results 2

	LD Model (3)	TD Model (4)
TI	0.0598***	0.304***
CE	0.0894***	0.104***
URB	0.541***	1.414***
INVE	0.330***	0.441***
_cons	18.74***	3.592***
N	600	600
R <sup>2</sup>	0.918	0.943

Table 3 and Table 4 show the regression results. In addition, the R<sup>2</sup> results for all 8 models are greater than 0.5, indicating that all models are well fitted.

Note. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

The regression results of models (1) and (2) show the impact of logistics development and tourism development on low-carbon economy respectively. The results show that the coefficients of logistics development and tourism development are all significantly positive at the significant level of 1%, and they are still significantly positive at the significant level of 5% in the regression results of the models (5), (6), (7) and (8) with interaction terms, which indicates that logistics development and tourism development have positive impacts on low-carbon economy, thus hypothesis 1 is verified.

From the regression results of models (5) and (7), we can see that the coefficients of each interaction item are significantly positive at the level of 1%, which indicates that technological innovation plays a significant positive moderating role in the development of

logistics and tourism to promote low-carbon economy. We can also find that the interaction term coefficients are significantly positive at the level of 1% from the regression results of models (6) and (8), which indicates that the use of clean energy also plays a significant positive moderating role in the development of logistics and tourism to promote low-carbon economy.

The results of models (3) and (4) show the impacts of technological innovation and clean energy on the logistics development and tourism development respectively. The results show that the coefficients of technological innovation are significantly positive at the level of 1%, which indicates that technological innovation has positive impacts on the logistics development and tourism development; the coefficients of clean energy are significantly positive at the level of 1%, which shows that clean energy also has positive impacts on them, and thus hypothesis 2 and hypothesis 5 are verified.

### 5.2 Threshold Effects Regression

According to the fixed effect regression results of the models (5), (6), (7) and (8), this paper uses Wald test to further verify hypothesis 3, 4, 6 and 7.

Table 5. Threshold effect test results of each threshold variables

Model	Threshold	Threshold type	Threshold values	P values	95% Conf. Interval
(9)	TI	Single	5.5134***	0.0025	[5.4293,5.5759]
		Double	10.0524*	0.0640	[9.9714,10.0987]
(10)	TI	Single	5.5759***	0.0025	[5.4714,5.6699]
		Double	10.0524**	0.0360	[9.9749,10.0987]
(11)	CE	Single	2.8792*	0.0520	[2.8517,2.8904]
		Double	/	/	/
(12)	CE	Single	1.8563*	0.0660	[1.7863,1.9199]
		Double	/	/	/

Table 5 shows the threshold effect test results after 500 repeated sampling tests.

Note. \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ ; “/” Indicates that the threshold is not significant.

From Table 5 we can see that there exist significant double threshold effects in models (9) and (10), while there are significant single threshold effects in models (11) and (12). Therefore, we can draw the following conclusions: (1) Technological innovation has double threshold effects in the process of logistics development and tourism development promoting low-carbon economy; (2) clean energy has single threshold effects in the process of logistics development and tourism development promoting low-carbon economy.

According to the above results, this paper conducts threshold effect regression analysis on models (9), (10), (11) and (12).

Table 6. Threshold effect regression results for each threshold variables

	Model (9)	Model (10)	Model (11)	Model (12)
Variables	Coef.	Coef.	Coef.	Coef.
LD*I (TI≤5.5134)	0.302*** (0.0703)			
LD*I (5.5134<TI≤10.0524)	0.318*** (0.0702)			
LD*I (TI> 10.0524)	0.353*** (0.0707)			
TD*I (TI≤5.5759)		0.239*** (0.0448)		
TD*I (5.5759<TI≤10.0524)		0.261*** (0.0446)		
TD*I (TI> 10.0524)		0.322*** (0.0454)		
LD*I (RE≤2.8792)			0.251*** (0.0803)	
LD*I (RE> 2.8792)			0.269*** (0.0805)	
TD*I (RE≤1.8563)				0.306*** (0.0491)
TD*I (RE> 1.8563)				0.333*** (0.0493)
URB	-0.504** (0.198)	-0.757*** (0.208)	-0.257 (0.222)	-0.628*** (0.230)
INVE	0.134*** (0.0442)	0.0879* (0.0460)	0.191*** (0.0496)	0.0580 (0.0514)
_cons	6.277***	11.27***	6.206***	10.05***

Table 6 shows the regression results of the models (9), (10), (11) and (12).

Note. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

### 5.2.1 Threshold Regression Analysis of Technological Innovation

According to the threshold regression results of model (9), we can see that logistics development has a significant double threshold effect on low-carbon economy at a significant level of 10% when technological innovation is seen as a threshold variable. Specifically, when TI is lower than the first threshold (5.5134), the regression coefficient of logistics development is 0.302 at a significant level of 1%; when the TI is between the first threshold value (5.5134) and the second threshold value (10.0524), the regression coefficient is 0.318 at the 1% significant level; when TI is higher than the second threshold (10.0524), the regression coefficient is 0.353, which is significantly positive at the 1% significant level. Thus, it can be seen that as the level of technological innovation moves from low threshold to



high threshold, the promotion of logistics development on low-carbon economy is gradually enhanced, which verifies hypothesis 3.

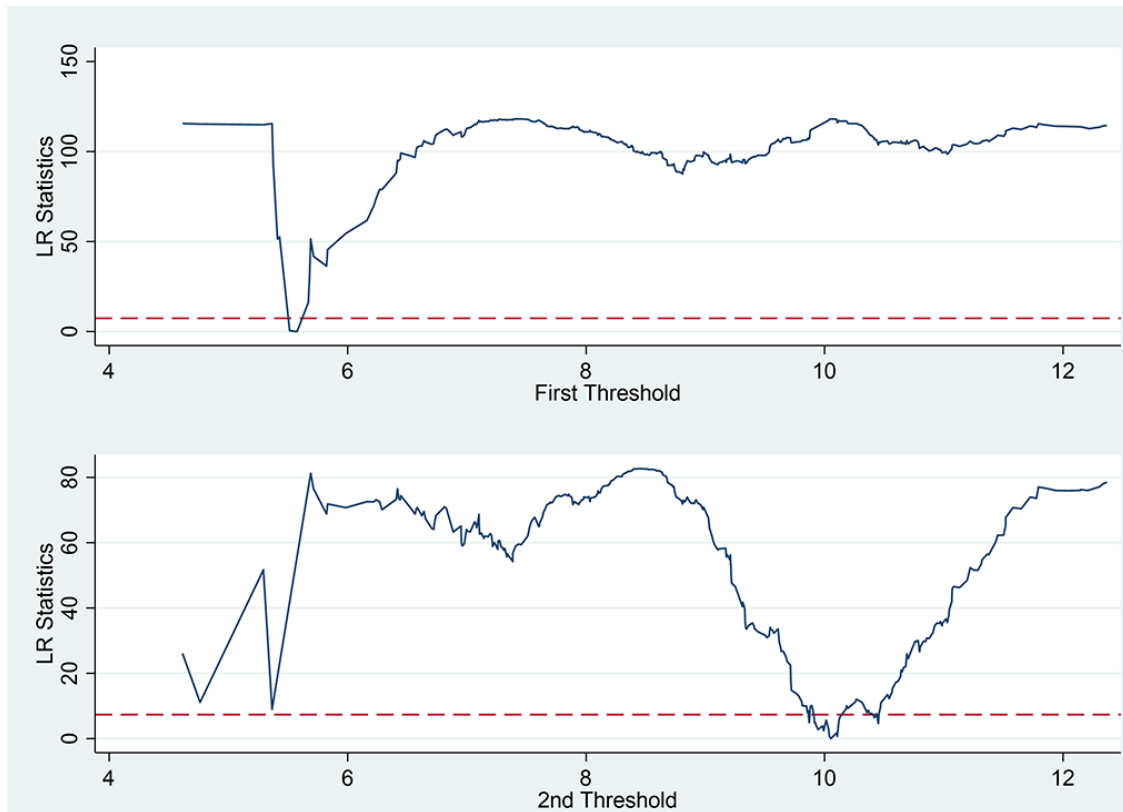


Figure 2. Double threshold LR estimation diagram of model (9)

Figure 2 shows the likelihood ratio function of model (9) with double threshold estimated values of 5.5134 and 10.0524, respectively, thus, the threshold is valid.

According to the threshold regression results of model (10), we can see that the tourism development has a significant double threshold effect on low-carbon economy at a significant level of 5% when technological innovation is seen as a threshold variable. Specifically, when TI is lower than the first threshold (5.5759), the regression coefficient of tourism development is 0.239 at a significant level of 1%; when the TI is between the first threshold value (5.5759) and the second threshold value (10.0524), the regression coefficient is 0.261 at the 1% significant level; when TI is higher than the second threshold (10.0524), the regression coefficient is 0.322, which is significantly positive at the 1% significant level. Thus, it can be seen that as the level of technological innovation moves from low threshold to high threshold, the promotion effect of tourism development on low-carbon economy is gradually enhanced, which verifies hypothesis 4.

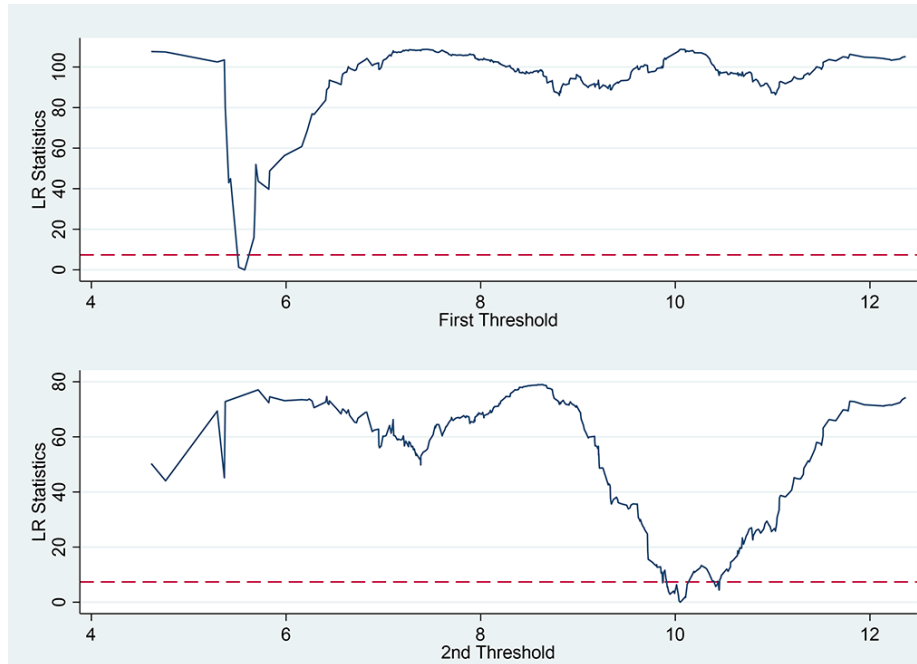


Figure 3. Double threshold LR estimation diagram of model (10)

Figure 3 shows the likelihood ratio function of model (10) with double threshold estimated values of 5.5759 and 10.0524, respectively.

### 5.2.2 Threshold Regression Analysis of Clean Energy

According to the threshold regression results of model (11), we can see that the logistics development has a significant single threshold effect on low-carbon economy at a significant level of 10% when clean energy is seen as a threshold variable. Specifically, when the CE is lower than the threshold value (2.8792), the regression coefficient of logistics development is 0.251 at a significant level of 1%; when the CE is higher than the threshold value (2.8792), the regression coefficient is 0.269 at a significant level of 1%. Thus, it can be seen that as the use of clean energy moves from low threshold to high threshold, the promotion of logistics development on low-carbon economy is gradually enhanced, which verifies hypothesis 6.



Figure 4. Single threshold LR estimation diagram of model (11)

Figure 4 shows the likelihood ratio function for the single threshold estimates in model (11), which is 2.8792.

According to the threshold regression results of model (12), we can see that the tourism development has a significant single threshold effect on low-carbon economy at a significant level of 10% when clean energy is seen as a threshold variable. Specifically, when CE is lower than the threshold value (1.8563), the regression coefficient of tourism development is 0.306 at a significant level of 1%; when the CE is higher than the threshold (1.8563), the regression coefficient is 0.333 at the significant level of 1%. Thus, it can be seen that as the use of clean energy moves from low threshold to high threshold, the promotion of tourism development on low-carbon economy is gradually enhanced, which verifies hypothesis 7.

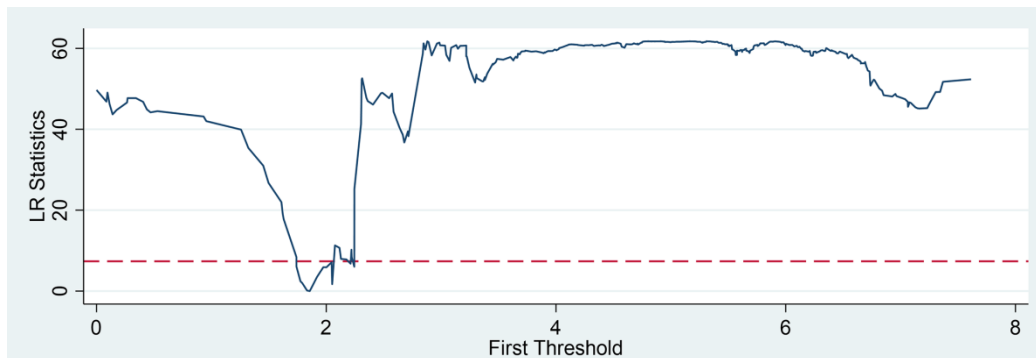


Figure 5. Single threshold LR estimation diagram of model (12)

Figure 5 shows the likelihood ratio function for the single threshold estimates in model (12), which is 1.8563.

### 5.3 Regional Heterogeneity Analysis

According to the different threshold values shown in Table 5, this paper further divides the samples into different intervals, and the specific number of provinces in each interval from 2000 to 2019 can be seen in Table 7, Table 8, Table 9 and Table 10.

Table 7. Number of provinces in the TI threshold interval in model (9)

Threshold interval	2000	2005	2010	2015	2019
$TI \leq 5.5134$	3	3	0	0	0
$5.5134 < TI \leq 10.0524$	27	26	23	12	11
$TI > 10.0524$	0	1	7	18	19

Table 7 shows the specific number of provinces in model (9) in each interval from 2000 to 2019.

Table 8. Number of provinces in the TI threshold interval in model (10)

Threshold interval	2000	2005	2010	2015	2019
$TI \leq 5.5759$	3	3	0	0	0
$5.575 < TI \leq 10.0524$	27	26	23	12	11
$TI > 10.0524$	0	1	7	18	19

Table 8 shows the specific number of provinces in model (10) in each interval from 2000 to 2019.

Table 9. Number of provinces in the CE threshold interval in model (11)

Threshold interval	2000	2005	2010	2015	2019
$CE \leq 2.8792$	13	10	3	3	0
$CE > 2.8792$	17	20	27	27	30

Table 9 shows the specific number of provinces in model (11) in each interval from 2000 to 2019.

Table 10. Number of provinces in the CE threshold interval in model (12)

Threshold interval	2000	2005	2010	2015	2019
$CE \leq 1.8563$	5	5	2	0	0
$CE > 1.8563$	25	25	28	30	30

Table 10 shows the specific number of provinces in model (12) in each interval from 2000 to 2019.

It can be seen from Table 7 and Table 8 that from 2000 to 2019, the number of provinces in the low and medium threshold range of technological innovation gradually decreased, and the number of provinces in the high threshold range continued to increase. Similarly, it can be seen from Table 9 and Table 10 that the number of provinces in the low threshold range of clean energy continued to decrease from 2000 to 2019, and most provinces were in the high threshold range by 2019. This indicates that China's technological innovation level and clean energy use have achieved sustained development during the past decades. With the significant improvement of scientific research and the continuous increase of technological innovation, large-scale energy transformation measures have achieved good results, effectively promoting green and low-carbon development.

In order to further analyze the threshold effects of regional heterogeneity of technological innovation and clean energy in the processes of logistics development and tourism development on low-carbon economy, 30 provinces in Chinese Mainland are divided into eastern, central and western regions according to their geographical location (Guo & Cai, 2022), and three threshold panel regressions on them are performed respectively.

Table 11. The specific division of the three major regions in China

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

Table 11 shows the specific division of the three regions in China.

Table 12-1. Regression results 1 of threshold effect in different regions

Variables	Model (9)			Model (10)		
	East	Central	West	East	Central	West
LD*I ( $TI \leq \gamma_1$ )	0.948***	0.312**	0.405***			
LD*I ( $\gamma_1 < TI \leq \gamma_2$ )	0.997***	0.330***	0.511***			
LD*I ( $TI > \gamma_2$ )	1.090***					
TD*I ( $TI \leq \gamma_1$ )				0.444***	0.176***	0.233***
TD*I ( $\gamma_1 < TI \leq \gamma_2$ )				0.517***	0.198***	0.248***
TD*I ( $TI > \gamma_2$ )				0.668***		0.408***
Control	√	√	√	√	√	√

Table 12-2. Regression results 2 of threshold effect in different regions

Variables	Model (11)			Model (12)		
	East	Central	West	East	Central	West
LD*I ( $CE \leq \gamma_1$ )	0.920***	0.398***	0.460***			
LD*I ( $CE > \gamma_2$ )	0.950***	0.412***	0.530***			
TD*I ( $CE \leq \gamma_1$ )				0.535***	0.114*	0.260***
TD*I ( $CE > \gamma_2$ )				0.577***	0.139**	0.372***
Control	√	√	√	√	√	√

Table 12 shows the threshold regression results of model (9), (10), (11) and(12).

Note. \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ ; “/” Indicates that the threshold is not significant.

From Table 12 we can see that the regression results of the samples divided into three groups according to geographical location are basically similar to the overall regression results in Table 6, but there are regional heterogeneity threshold effects, i.e., the regression coefficients of eastern regions are higher than those of central and western regions. Specifically, from the results of model (9) and model (10) we can see that, with the improvement of the level of technological innovation, the promotion of logistics development and tourism development in eastern regions on low-carbon economy are stronger than that in the central and western regions; from model (11) and model (12) we can see that, with the increase in clean energy use, the promotion effects of logistics development and tourism development on low-carbon economy in central and west regions are similar, while the promotion of logistics development and tourism development in the eastern region on the low-carbon economy are significantly stronger than that in the central and western regions.

To sum up, this paper believes that due to the particularity of different regions, logistics development and tourism development affected by the level of technological innovation and the use of clean energy have different effects on the low-carbon economy. Detailed explanations are as follows:

On the one hand, due to the high level of economic development in the eastern region, it has stronger advantages in green technology innovation with technology, talents and knowledge as the elements, and has a strong ecological protection awareness and green demand; however, central and western regions have relatively disadvantaged in R&D investment, talent management and energy efficiency due to the limitation of economic development

level. Therefore, the improvement of the level of technological innovation in the eastern regions has a more obvious role in promoting the low-carbon development of logistics, tourism and economy.

On the other hand, the eastern regions with lower energy intensity are less dependent on fossil energy, and the economic costs of developing clean energy are lower, so the low-carbon economy is more mature; however, due to the high energy intensity, the economic development of the central and western regions is highly dependent on fossil energy, so there are huge obstacles in the transition process of gradually replacing fossil energy with clean energy, leading to a relatively immature low-carbon economy. Based on this, the increased use of clean energy in eastern regions can further promote the low-carbon development of logistics, tourism and economy.

## 6. Robustness Test

In order to avoid the instability of the empirical model and reduce the influence caused by the extreme value of the sample, according to Li et al. (2021), this paper removes the samples with the highest and lowest 1%, 5% and 10% of technological innovation or clean energy, and then conducts a threshold model test for the remaining 28, 26 and 24 provinces respectively to study the robustness of the above results.

Table 13-1. Threshold effect regression results 1 of excluding extreme values

Variables	Model (9)			Model (10)		
	28	26	24	28	26	24
LD*I ( $TI \leq \gamma_1$ )	0.425***	0.405***	0.497***			
LD*I ( $\gamma_1 < TI \leq \gamma_2$ )	0.441***	0.421***	0.512***			
LD*I ( $TI > \gamma_2$ )	0.537***	0.511***				
TD*I ( $TI \leq \gamma_1$ )				0.192***	0.173***	0.117***
TD*I ( $\gamma_1 < TI \leq \gamma_2$ )				0.215***	0.197***	0.135***
TD*I ( $TI > \gamma_2$ )				0.372***	0.350***	0.154***
Control	√	√	√	√	√	√

Table 13-2. Threshold effect regression results 2 of excluding extreme values

Variables	Model (11)			Model (12)		
	28	26	24	28	26	24
LD*I ( $CE \leq \gamma_1$ )	0.260***	0.295***	0.208***			
LD*I ( $CE > \gamma_2$ )	0.279***	0.386***	0.221***			
TD*I ( $CE \leq \gamma_1$ )				0.322***	0.316***	0.286***
TD*I ( $CE > \gamma_2$ )				0.348***	0.344***	0.337***
Control	√	√	√	√	√	√

Table 13 shows the test regression estimation results which to study the robustness of the above results.

Note. \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ ; “/” Indicates that the threshold is not significant.

According to Table 13, we can see that the regression coefficient values and significance levels of each model are similar to those in Table 6, and there is no significant difference among the above threshold effect results and those of the whole sample, therefore, it can be inferred that the threshold models and results constructed in this paper have good robustness.

## 7. Conclusions and Implications

Based on the panel data of 30 provinces in China from 2000 to 2019, this paper uses a fixed effect model and threshold effect model to study the non-linear threshold impacts of logistics development and tourism development on the low-carbon economy from the perspectives of technological innovation and clean energy. The main conclusions are as follows: firstly, logistics development and tourism development can promote low-carbon economy; secondly, with the improvement of technological innovation and the increase in the use of clean energy, the promotion of logistics development and tourism development on low-carbon economy are gradually enhanced; finally, in the process of logistics development and tourism development promoting low-carbon economy, the threshold effects of technological innovation and clean energy have obvious regional heterogeneity: in each threshold interval, the development of logistics and tourism in the eastern regions has a stronger role in promoting the low-carbon economy than in the central and western regions.

Based on the above conclusions, this paper puts forward the following suggestions:

(1) In terms of logistics development: Firstly, we should publicize the concept of low-carbon logistics, strengthen the awareness of low-carbon logistics, and promote the industrial structure innovation of the logistics industry through strategic implementation, policy support and other measures; secondly, we should reasonably plan all logistics nodes to reduce logistics costs and energy consumption, especially for the logistics enterprises in eastern regions, and exploit modern intelligent logistics technology to improve the logistics informatization level and low-carbon logistics operation efficiency; finally, we should encourage the use of environmental protection and low-carbon logistics equipment, and increase the proportion of clean energy in the energy consumption of the logistics industry to optimize the logistics energy structure.

(2) In terms of tourism development: Firstly, we should advocate the concept of low-carbon travel and green consumption, actively develop public tourism transportation with low per capita energy consumption, and encourage the use of clean energy transportation to reduce the energy consumption of tourism transportation and create an environment-friendly tourism transportation; secondly, we should strengthen the monitoring and management of tourism, transportation, accommodation and other high emission industries, and reduce their carbon dioxide emissions by formulating environmental policies for the tourism industry; finally, we should pay attention to the marketing and publicity of low-carbon tourism, especially in eastern regions. For example, low-carbon tourism products should be designed and developed in these regions to achieve the low-carbon development of tourism while promoting energy conservation and emission reduction.

(3) In terms of regional heterogeneity: On the one hand, the government should actively



guide the flow of high-tech talents across regions, strengthen technical exchanges and cooperation among regions, and improve the efficiency of technological R&D to develop innovative industries in central and western regions; on the other hand, the government should further increase subsidies and support for the clean energy industry in central and western regions, stimulate the transformation of energy structure and economic development mode, and alleviate the imbalance of low-carbon development in China.

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