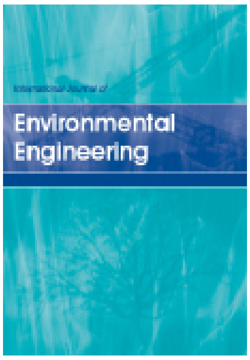

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The efficiency of green total factor productivity of the logistics industry in the Yangtze River Economic Belt: a spatial econometric analysis

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The efficiency of green total factor productivity of the logistics industry in the Yangtze River Economic Belt: a spatial econometric analysis

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Abstract: This paper measures the efficiency and analyses the spatial-driven mechanism of GTFP of the logistics industry from 2009 to 2018. An upward trend was shown regarding the GTFP of the logistics industry, and the Moran's I index showed a spatial positive correlation. The direct and indirect effects of scientific and technological innovation, economic development, industrial structure, and urbanisation were positive regarding the GTFP of the logistics industry, while the direct effects of scientific and technological innovation, economic development, industrial structure, and urbanisation were observed to be significantly greater than the indirect effects on the GTFP of the logistics industry. The direct and indirect effects of FDI, logistics energy intensity, and transportation intensity were negative regarding the GTFP of the logistics industry, and the direct effects were significantly greater than the indirect effects.

Keywords: logistics industry; green total factor productivity; GTFP; SDM model; Malmquist model; Yangtze River Economic Belt.

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1 Introduction

With the shortage of resources and the deterioration of the environment in the world the environmental issues of have aroused widespread concern around the world (Xiao et al., 2019). Green total factor productivity (GTFP) is a measurement system that integrates resource consumption and environmental pollution and represents an important basis for evaluating high-quality development of the logistics industry (Lin and Chen, 2018; Liu and Xin, 2018). The Yangtze Economic Belt includes 11 provinces, with a total economic aggregate of more than 40% and a total land area accounting for 21.4% of China. The development of the logistics industry in the Yangtze Economic Belt played a vital role in the development of the Chinese logistics industry by responding to the idea of high-quality economic development according to state and coordinating the relationship between the logistics industry and high-quality energy and environmental development. Improving GTFP is the best way to build a modern logistics industry and is also the only way to develop the logistics industry in the Yangtze Economic Belt in a high-quality manner. However, questions remain regarding the nature of logistics GTFP in the Yangtze Economic Belt, the factors affecting its spatial mechanism, and methods to improve these areas.

Under the green development background, the motivation of this study is to measure logistics GTFP based on the perspective of resources and analysed the internal mechanism of logistics industry GTFP in the Yangtze River Economic Belt, from the perspective of spatial. This research can enable a more scientific approach to evaluating green development quality of the logistics industry and provides guidance for the green development of the GFTP of the logistics industry in the Yangtze Economic Belt. Therefore, it is of great theoretical and practical significance to study logistics GTFP in the Yangtze Economic Belt.

2 Literature review

In recent years, studies regarding the efficiency of the logistics industry have become a hot field of research. In the aspect of static efficiency, for example, Markovits-Somogyi measured the logistics efficiency of 29 European countries by combining data envelopment analysis (DEA) and AHP (Markovits-Somogyi and Bokor, 2014), Wu et al. (2012) analysed the operational efficiency of Chinese logistics enterprises, while Wang et al. (2018) studied highway logistics efficiency and its influencing factors. Zhou et al. (2008) used CCR and BCC models combined with a step-wise regression method. Regarding the aspect of dynamic efficiency in the logistics industry, Zhang et al. (2015) calculated the dynamic change and regional differences in total factor energy efficiency of China's logistics industry, whereas Cheng and Chen (2018) calculated the total factor of environmental productivity of the logistics industry in the Yangtze River Economic Zone. Pei and Mu (2021) used the Malmquist-Luenberger (ML) model to calculate the total factor productivity of logistics industry in 13 cities in Beijing-Tianjin-Hebei region from 2009 to 2019. Zhang and Sun (2020) used the SBM-ML model to measure the green logistics industry and the spatial panel econometric model is used to analyse the influence factors and spatial spillover effects of GTFP in 30 provinces of China from 2004 to 2016. Liang et al. (2020) measured and decomposed GTFP of the logistics industry in 13 cities Jiangsu province from 2006 to 2018. Liang and Li (2021) calculated the spatial spillover effect of transportation infrastructure on the GTFP using the ML index and the dynamic spatial Durbin model in 30 provinces China from 2005 to 2017. Li et al. (2020) measured and calculated tourism GTFP in China between 2007 and 2018. However, GTFP of the logistics industry can be further studied in the Yangtze River Economic Belt. Such as, the existing studies no in-depth report on the spatial-driven mechanism of the logistics GTFP in the Yangtze River Economic Belt. GTFP in the logistics industry contains many logistics elements which can be used as explanatory variables to avoid information distortion caused by a single indicator as an explanatory variable. The impact of environmental constraints on the development of the logistics industry can also be considered. Previous literature was mainly based on national or provincial perspectives, with little research related to the Yangtze Economic Belt and no GTFP or spatial mechanism analyses regarding the logistics industry, and little attention paid to the dependence of logistics development in adjacent regions. The SDM model could better explain the driving factors and spatial mechanism of GTFP in the logistics industry; therefore, it is of great practical significance to study logistics GTFP in the Yangtze Economic Belt and to analyse its spatial mechanism in order to promote this field.

3 Research model and data sources

3.1 Malmquist index model

Three methods were previously described in the literature to measure total factor productivity, namely, the Solow residual method of the Cobb-Douglas function, stochastic frontier analysis (SFA), and the Malmquist index model of the DEA method. The Malmquist index model has more advantages, with the choice of input or output indicators possibly being inconsistent. Based on the method proposed by Farrell (1957), we used CO_2, which is not the expected output of the logistics industry, as the output variable of GTFP. The Malmquist productivity index can be divided into the product of technological change and technological efficiency change. Based on the above analysis, an output-oriented ML index model was constructed, as described in equations (1), (2), and (3):

$$ML_t^{t+1} = \frac{1+\vec{D}_0^G\left(x^t, y^t, b^t; y^t, -b^t\right)}{1+\vec{D}_0^G\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}\right)} = Tech_t^{t+1} \times Effch_t^{t+1} \tag{1}$$

$$Tech_t^{t+1} = \frac{1+\vec{D}_0^G\left(x^t, y^t, b^t; y^t, -b^t\right)}{1+\vec{D}_0^t\left(x^t, y^t, b^t; y^{t+1}, -b^t\right)} \times \frac{1+\vec{D}_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}\right)}{1+\vec{D}_0^G\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}\right)} \tag{2}$$

$$Effch_t^{t+1} = \frac{1+\vec{D}_0^t\left(x^t, y^t, b^t; y^t, -b^t\right)}{1+\vec{D}_0^G\left(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}\right)} \tag{3}$$

Formula (1) represents ML index, which is decomposed of Tech and Effch. Formula (2) represents Tech, which is the change index of technological progress from the t phase to the $t + 1$ phase. Formula (3) represents Effch, which is the change index of technical efficiency from t to $t + 1$ period (Liu and Sun, 2018). Thus, Effch represents the extent to which each unit's undesired and desired outputs are close to the production frontier. If $Effch > 1$, the unit of production is closer to the $T + 1$ stage than to the stage, and its technical efficiency can be considered to increase. For example, when $Tech > 1$, the production possibility frontier changes in the direction of less expected output and more expected output.

Based on the above model and relevant literature (Zhou et al., 2008; Zhang et al., 2015), we selected the following input and output variables of the logistics industry.

1. Input variables: The logistics industry mainly considers three kinds of important input variables, i.e., capital, energy, and labour. The input variables were therefore determined to be fixed capital stock (RMB billion), energy consumption (RMB 10,000 tons of standard coal), and employee (RMB 10,000) assets.
2. Expected output variables: The added value of the logistics industry (billion yuan) was used here to express the output variables of the logistics industry. The non-expected output variable was represented by the carbon dioxide (CO_2) emissions (10,000 tons) from the energy of the logistics industry.

3.2 SDM model

This article was based on the existing research literature (Marbuah and Amuakwa-Mensah, 2017). In this work, the SDM model was used to study the spatial influence of GTFP in the Yangtze River Economic Belt, with the SDM model represented by formula (4):

$$Y_i = \rho WY_i + \alpha_i l_N + X_i \beta + WX_i \theta + \varepsilon \tag{4}$$

where Y_i is the explanatory variable, X_i is the explanatory variable, α_i is the constant, W is the space weight, N is the parameter term vector, $\alpha_i l_N$ is the sum of the constant term, ρ is the space autoregressive coefficient, β, θ is the estimated parameter, and ε is the residual term. $X_i\beta$ represents the marginal degree of influence of the explanatory variables in the region on the explanatory variables in the adjacent region, ρWY_i represents the spatial lag term, i.e., the marginal degree of influence of the explanatory variables in the adjacent region on the explanatory variables in the region, and $WX_i\theta$ represents the marginal degree to which the explanatory variables of adjacent regions affect the explanatory variables of the region.

3.3 Spatial decomposition model

The marginal effects of the variables were unable to be directly explained by using the SDM model. Therefore, according to the viewpoint of LeSage and Pace (2009), the SDM model can be used to decompose the total effects into direct and indirect effects using the partial differential method. In this work, the direct and indirect effects of each factor on the GTFP spillover of the logistics industry in the Yangtze River Economic Belt were analysed respectively on the basis of formula (4), which can be decomposed into formulae (5) and (6), as follows:

$$\frac{\partial Y_i}{\partial x_i} = (I - \rho W) W \beta \tag{5}$$

$$\left[\frac{\partial Y}{\partial X_{1K}} \quad \cdots \quad \frac{\partial Y}{\partial X_{NK}}\right]_t = \begin{bmatrix} \frac{\partial Y_1}{\partial X_{1K}} & \cdots & \frac{\partial Y_1}{\partial X_{NK}} \\ \cdots & \cdots & \cdots \\ \frac{\partial Y_N}{\partial X_{1K}} & \cdots & \frac{\partial Y_N}{\partial X_{NK}} \end{bmatrix}$$
$$= (I - \delta W)^{-1} \begin{bmatrix} \beta_K & W_{12}\theta_K & \cdots & W_{1N}\theta_K \\ W_{21}\theta_K & \beta_K & \cdots & W_{2N}\theta_K \\ \vdots & \vdots & \vdots & \vdots \\ W_{N1}\theta_K & W_{N2}\theta_K & \cdots & \beta_K \end{bmatrix} \tag{6}$$

where $I = [1, 0, \ldots, 0]n$. The average value of the main diagonal elements in the matrix in formula (6) represents the direct effect of the variable, the average value of the non-main diagonal elements represents the indirect effect of the variable, and the total effect is the sum of the direct and indirect effects.

3.4 Data sources

The research samples included 11 provinces and cities in the Yangtze River Economic Belt. This study divided in the Yangtze River Economic Belt into three regions (Liu and Han, 2021): the downstream regions, (including Jiangsu, Zhejiang and Shanghai), the midstream regions, (including Hubei, Hunan, Jiangxi and Anhui) and the upstream regions, (including Chongqing, Sichuan, Guizhou and Yunnan), excluding areas with severe data loss. To facilitate comparison, the data used in the research were mainly obtained from official statistical reports, such as the China Statistical Yearbooks 2010–2019 and the China fixed assets investment statistics yearbook.

4 Results and analysis

4.1 The results of the logistics industry GTFP in the Yangtze economic belt

Solver 5.0 software and the Malmquist index model were used to measure the logistics industry GTFP from 2009 to 2018, as shown in Table 1.

As seen from Table 1, the logistics industry GTFP changed from 2009 to 2018 in the Yangtze Economic Belt with an average value of 1.010. The lowest coefficient of the GTFP index was 0.995 for each province from 2014 to 2015 in the Yangtze Economic Belt, and the highest coefficient was 1.037 from 2017 to 2018. Finally, the change in the average value of green technology progress in the logistics industry was 1.004 from 2009 to 2018, and the change in average value of green technology efficiency was 1.011. Meanwhile, from the GTFP of the logistics industry in the Yangtze River Economic Belt into three regions the average coefficient of the GTFP index was 1.012 in the upper reaches, the average coefficient of the GTFP index was 1.026 in the middle reaches, and the average coefficient was 1.038 in the lower reaches from 2009 to 2018.

Table 1 2009–2018 results of GTFP in the logistics industry

Time and region	*Green production index*	*Green technological progress*	*Green technology efficiency*
2009–2010	1.012	0.999	1.013
2010–2011	1.014	1.027	0.988
2011–2012	1.020	0.996	1.025
2012–2013	1.012	1.013	0.999
2013–2014	1.043	1.022	1.021
2014–2015	0.955	0.997	0.998
2015–2016	0.971	0.971	1.000
2016–2017	1.023	1.000	1.023
2017–2018	1.017	1.010	1.007
2018–2019	1.037	1.012	1.025
Mean value	1,010	1.004	1.011
Upstream	1.012	1.038	0.975
Midstream	1.026	1.013	1.013
Downstream	1.038	1.001	1.037

4.2 Spatial correlation of GTFP in the Yangtze River Economic Belt

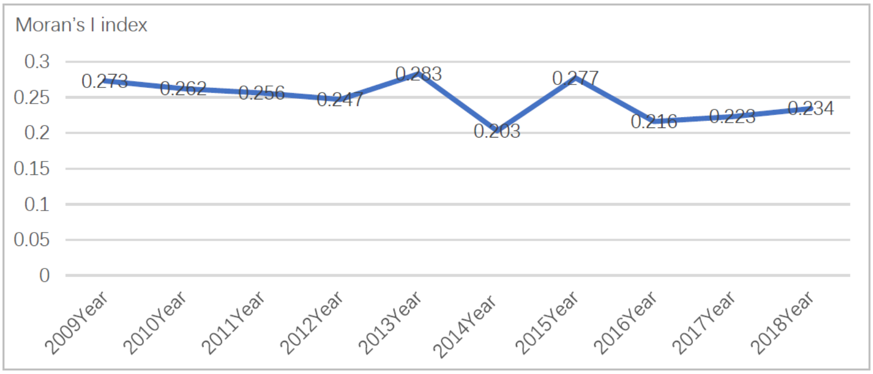
Previous literature demonstrated that spatial correlation was a prerequisite for the application of spatial econometric models, with global spatial correlation used to analyse the spatial correlation of spatial data in the whole region. In general, Moran's I index can be used as a measure of global spatial correlation, with formula (7), described as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}\left(x_j - \overline{x}\right)^2} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{s^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{7}$$

where n represents the number of provinces in the Yangtze River Economic Belt, X_i and x_j represent the variables of provinces I and j respectively, and W_{ij} represents the spatial weight and the average value of the variables. The index value of Moran's I is generally between –1 and 1. When Moran's I is greater than 0, it is considered to be a spatially positive correlation, whereas, when Moran's I is less than 0, it is considered to be a spatially negative correlation. When Moran's I is equal to 0, there is no correlation.

In this paper, Stata 15.0 was used to calculate the value of Moran's I index of the GTFP in the Yangtze Economic Belt. The results are shown in Figure 1, with the value of Moran's I index of the GTFP clearly fluctuating from 0.20 to 0.30 in the Yangtze Economic Belt.

Figure 1 2009–2018 year results of GTFP Moran's I index (see online version for colours)



4.3 Spatial mechanism regarding the logistics industry GTFP in the Yangtze economic belt

4.3.1 Empirical models

According to the relevant research literature (Li and Liu, 2020), the spatial mechanism of the logistics GTFP is mainly affected by economic development, environmental impact, and scientific and technological innovation. Therefore, seven indexes were used as explanatory variables from the three angles of science and technology innovation, economic development, and infrastructure.

The explanatory variables included technological innovation, which mainly considers technological innovation capability and adopts the number of patents granted by each region; industrial structure, which adopts the logistics industry added value by taking the proportion of regional GDP as a variable agent; foreign investment (FDI), which adopts the proportion of fixed assets investment in the logistics industry using the proportion of foreign direct investment as a variable agent; urban, which adopts the proportion of the resident population to total population; economic development, which adopts the per capita GDP, and transportation intensity, which adopts the use of comprehensive logistical turnover according to the proportion of regional GDP. The above variables were selected and an SDM empirical model setting formula [formula (8)] was obtained by decomposing and combining formula (4) as follows:

$$\begin{aligned}\text{GTFP}_{it} &= \alpha_i l_N + \rho W(\text{GTFP}) + \beta_0 \ln(\text{Ino}) + \theta_0 W \ln(\text{Ino}) + \beta_1 \text{eff} + \theta_1 W\text{eff} \\ &+ \beta_2 \ln(\text{pgdp}) + \theta_2 W \ln(\text{pgdp}) + \beta_3 \text{indus} + \theta_3 W\text{indus} + \beta \text{tti} + \theta_4 W\text{tti} + \beta_5 \ln(\text{FDI}) \\ &+ \theta_5 W \ln(\text{FDI}) + \beta_6 \text{Urban} + \theta_6 W\text{Urban} + \mu_i + \mu_n + \varepsilon\end{aligned} \quad (8)$$

where $GTFP_{it}$ is the GTFP of logistics industry, μ_I is the time effect, and μ_n is the individual effect.

4.3.2 Empirical results

Based on the above Moran's I index results, the non-spatial model was rejected. From the test results, Wald's test estimate was 46.77 and it was significant at the 1% level. Based on the results of Elhorst's study, the model was considered to be more suitable if the test results were all significant at the 10% level. Hausman's test was 1.33, but the p-value was 0.6428, therefore, the original hypothesis was accepted and the SDM model was chosen to analyse the random effects. Meanwhile, according to Robust's test, the results of the calculation are reliable. For the SDM model, the addition of spatial lag term could not reflect the marginal effects of the variables, therefore, the partial differential equation was used to further decompose the space effect into direct and indirect effects. As seen in Table 2, the direct effects of sci-tech innovation, economic development, industrial structure, and urbanisation were positive, reaching 0.3817, 0.2115, 0.2217, and 0.0921. The indirect effects of 0.1911, 0.1154, –0.0989, and 0.1137 were positive, except the indirect effect of industrial structure, with all of them passing the 10% significance test. The other variables, i.e., the direct effects of logistics energy intensity, transportation intensity, and foreign direct investment, demonstrated negative effects on logistics GTFP, reaching –0.2217, –0.2312, and –0.1390. Regarding the indirect effects, the energy intensity of logistics, the intensity of transportation, and the existence of negative space spillover effects returned results of –0.1390, –0.0989, –0.0606, and –0.0221.

Table 2 Direct, indirect, and total effects of GTFP

Variables	*Direct effect*	*Indirect effect*	*Total effect*
Technological innovation capability (lnino)	0.2817*	0.1911*	0.4728***
Energy intensity of material flow (Eff)	–0.2217**	–0.0989*	–0.1228**
Level of economic development (lnpgdp)	0.2115	0.1154**	0.3269**
Industrial structure (Indus)	0.2217**	–0.0989	0.1228**
Traffic intensity (Tti)	–0.2312**	–0.0606**	–0.2918**
Foreign direct investment (lnFDI)	–0.1390**	–0.0221**	–0.1611**
Urbanisation (Urban)	0.0921*	0.1137	0.2058***

Note: *, **, *** means passing the significance test at the 10%, 5% and 1% levels.

5 Results analysis

Herein, the reasons behind the aforementioned impacts are discussed.

1. As seen in Table 1, the GTFP of the logistics industry fluctuated and rose in the Yangtze Economic Belt, indicating that the development of the logistics industry gradually changed from the original development mode, with a focus on improving the GTFP of the logistics industry while reducing the impact of the logistics industry on the environment. Compared with the middle and upper areas of the Yangtze River Economic Belt, the GTFP of the logistics industry in the lower zone was higher, indicating that the GTFP of the logistics industry was higher. A possible reason for this result was that the logistics industry in the lower reaches applied relatively advanced logistics technology, advanced management mode, talent gathering, and other factors. Therefore, the lower reaches presented higher GTFP results than the middle and upper reaches of the Yangtze River Economic Belt.
2. The results showed a positive spatial correlation regarding the GTFP of the logistics industry in the Yangtze River Economic Zone. The above research demonstrated the

ability to apply the spatial econometric model to analyse the GTFP of the logistics industry in the Yangtze Economic Belt.

3 As seen in Table 2, scientific and technological innovation, economic development, industrial structure, and urbanisation promoted the green development of the logistics industry in the region of the Yangtze Economic Belt, with significant spatial spillover effects. Scientific and technological innovation, economic development, industrial structure, and urbanisation were shown to be important driving forces for the promotion of GTFP in the Yangtze Economic Belt and logistics industry. As the intensity of scientific and technological innovation increases alongside the level of economic development, increases in the proportion of the economy output tertiary sector and the rate of urbanisation are expected to promote the green level of the logistics industry GTFP. Possible reasons for this include that scientific and technological innovation was shown to be conducive to the adoption of advanced logistics technology and new management models, the promotion and application of advanced green transport, storage, packaging, and other technologies and equipment, and the reduction of polluting emissions from the logistics industry, therefore enhancing logistics GTFP in the Yangtze Economic Belt. Further, a higher level of economic development was conducive to enhancing residents' awareness of the green environment, stimulating demand for green services, and prompting logistics enterprises to provide more environmentally friendly and energy-saving logistics services. The logistics industry in the Yangtze Economic Belt vigorously promoted the transformation and upgrade of the industrial structure while cultivating and expanding the emerging strategic logistics industry, with the emerging green logistics industry demonstrating obvious potential. Urbanisation was proven to be beneficial regarding the accumulation of labour force and production factors in the development of logistics in various regions of the Yangtze River Economic Belt, the promotion of high-quality logistics development, and the promotion of GTFP in this field. As the intensity of logistics energy, transportation, and foreign direct investment all increase, the green level of logistics GTFP in the Yangtze Economic Belt is expected to be restrained.

6 Conclusions and implications

The main research findings from the abovementioned results are as follows:

1 The GTFP of the logistics industry generally fluctuated with an upward trend from 2009 to 2018 in the Yangtze River Economic Belt. The GTFP of the logistics industry demonstrated significant spatial positive correlation characteristics in the Yangtze River Economic Belt.

2 Under the adjacent space weight matrix, the direct effects of science and technology innovation, economic development level, industrial structure, and urbanisation were shown to be positive on the GTFP of the logistics industry in the Yangtze River Economic Belt, whereas the indirect effects of technological innovation and the level of economic development were positive on the GTFP of the logistics industry in the Yangtze Economic Belt. The indirect effect of industrial structure negatively affected the GTFP of the logistics industry in the Yangtze River Economic Zone, but did not

pass the significance level test, whereas the indirect effect of urbanisation on the green total factor production of the logistics industry demonstrated a positive effect in the Yangtze River Economic Belt, but also did not pass the significance level test. The direct effects of foreign direct investment, logistics energy intensity, and transportation intensity were shown to negatively effect the GTFP of the logistics industry in the Yangtze Economic Zone, with the indirect effects of foreign direct investment, logistics energy intensity, and transportation intensity also showing negative effects.

This study not only attempted to measure logistics industry GTFP, but also analysed the internal mechanism of logistics industry GTFP in the Yangtze River Economic Belt, from the perspective of spatial. This paper, therefore, is theoretical innovative to some extent in its approach. Based on the above research the following suggestions are proposed.

First, the local government should formulate differentiated policies to accelerate the formation of logistics industry agglomerations linked by logistics park, and realise the green development of logistics industry integration.

Second, local logistics enterprises should raise their awareness of green development, realising the coordination of logistics activities with social and ecological benefits. On the one hand, the logistics enterprises should accelerate the development clean energy in place of traditional energy sources. On the other hand, the logistics enterprises should strengthen utilisation of green development technologies. the logistics enterprises should attach importance to the green logistics and the resulting energy saving, high efficiency, and low pollution.

Finally, the local government should adjust the logistics industrial structure in a timely, and increase the scale of logistics investment. Meanwhile, a green logistics system should be established, which will then give full play to the logistics spillover effect and achieve green logistics development, but attention should be paid to the logistics construction of all grades of logistics talent.

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Ming de Guo put forward the research idea and design research framework. Author analysed the data and evaluated the results, and have read and agreed to the published version of the manuscript.

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