Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 17 | No. 4 | pp. 1339-1346 | 2018

Original Research Paper | Open Access

Environmental Pollution and Measurement of Low-Carbon Logistics Efficiency in China's Logistics Industry

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 12-09-2018
Accepted: 05-11-2018

Key Words:
Transportation
Environmental pollution
Low-carbon logistics

ABSTRACT

The rapid growth of transportation brought about by the emerging logistics industry has resulted in substantial air, water, and noise pollution. Low-carbon logistics can effectively accomplish energy conservation and emission reduction, ultimately reducing environmental pollution and achieving coordinated development of the logistics industry and ecological environment. To further analyse the environmental pollution caused by the development of China's logistics industry, the efficiency of low-carbon logistics was measured. The literature on environmental pollution and low-carbon logistics efficiency caused by China and other countries logistics development has been combed, and then the causes of environmental pollution have been summarized. The DEA-BCC model was employed to measure the low-carbon logistics efficiency of 30 provinces (autonomous regions and municipalities directly under the central government) in China in 2016. Results show that the development of logistics industry in developed countries is early with relatively perfect system, thus causing less contamination. On the contrary, the pollution is more serious in developing countries because the logistics development mode is extensive. The logistics industry in China accounts for relatively high proportions of road transportation, causing air, water, and noise pollution. The provinces with a comprehensive efficiency value of 1 comprise only 20% of the national total, indicating that the overall low-carbon logistics efficiency in China is low. The provinces with a comprehensive efficiency value of 0.8 accounted for 36.67%, all located in the central and western regions of China. Policy recommendations for developing low-carbon logistics were put forward in five aspects, namely, improving the regulations on low-carbon logistics, establishing a carbon trading credit registration system, building a sound logistics recycling system, actively exploring low-carbon logistics education, and vigorously developing low-carbon logistics technologies. The research results of the study have a positive significance for fully understanding the status quo of environmental pollution caused by the logistics industry. The conclusions obtained can help promote low carbonization of the logistics industry and realize the coordinated development of the logistics industry and environment.

INTRODUCTION

As one of China's important pillar industries, the logistics industry has undergone rapid development in recent years. The total amount of social logistics has grown from 125.4 trillion yuan (RMB) in 2010 to 252.8 trillion yuan (RMB) in 2017, as shown in Figure 1. At the same time, the proportion of carbon emissions in the logistics industry to the total carbon emissions of the whole society is rising, which have reached around 18% in recent years. Wasted resources in the logistics industry, high carbon dioxide emissions, and insufficient output are prominent. The development of economic and social is facing increasing pressure with regard to energy conservation and emission reduction. China's logistics industry should address the following key issues: how to combine the current situation of environmental pollution caused by China's logistics industry, propose measures for the development of low-carbon logistics, regard low-carbon development as an important starting point for the transformation and upgrade of China's modern logistics industry, accelerate the construction of a low-carbon logistics system, and promote energy-saving and reduction in the industry. Aiming at these issues, the contribution rate of modern logistics industry to economic growth will be continuously improved.

Low-carbon logistics refers to modern logistics that always maintain minimum carbon emissions throughout the entire logistics process. Low-carbon logistics is a new requirement for developing the logistics industry with the advancement of the times and protecting the environment. Low-carbon logistics is an inevitable trend in developing logistics industry in the future. With the gradual deterioration of the environment and increasing number of natural disasters, developing economic models based on low energy consumption, low pollution, and low emissions is an important milestone in human civilization development. Low-carbon economy is critical for guiding the sustainable development of China's economy. To develop a low-carbon economy, extensive and low efficiency use of energy should be achieved firstly. China's logistics industry is facing such a dilemma as the country attaches great importance to the expansion of modern green logistics enterprises. The construction and planning of logistics parks promote inter-city regional economy, and low-carbon logistics can improve enterprise resource utilization efficiency. Therefore, analyzing the current situation of environmental pollution caused by the development of China's logistics industry to measure the efficiency of low-carbon logistics and propose measures to develop low-carbon logistics has positive reference values for the scientific and objective identification of carbon emission reduction technologies. The knowledge can also help in the search for methods of technical and management of carbon emission, which can reduce the energy consumption and energy pollution of logistics enterprises in the transportation process and alleviate the serious damage caused to the environment.

PREVIOUS STUDIES

With the rapid growth of social economy and the advancement of urbanization, the logistics industry plays an increasingly important role in urban development and people's lives. Despite the convenience brought about by the industry, it also causes environmental problems. Considerable research has been conducted in all over the world on the environmental pollution and low-carbon logistics development caused by the logistics industry. Oucher et al. (2012) completed a case study on a city in eastern Algeria and found that road traffic emissions seriously affect the local air environment. Mesjasz-Lech (2016) analysed how to determine the task of green logistics under the premise of reducing the negative environmental impact of urban households and entities. Maas et al. (2014) demonstrated that pollution prevention and service management capabilities can help third-party logistics providers achieve differentiated advantages. Sun et al. (2018) claimed that emissions brought about by crowded urban traffic are the most serious parts of urban air pollution in China. Chen et al. (2011) discussed the problems of green logistics in electrical retail trade and put forward the strategies and measures of green logistics in home appliance retailing. Yang et al. (2012) analysed the efficiency of urban logistics distribution network established under the background of carbon tax and suggested that strengthening the fine-tuning of network structure and resource allocation can help reduce costs and carbon emissions. Trappey et al. (2012) analysed the development of low-carbon island development projects in Penghu Islands, Taiwan and proposed green logistics measures to reduce carbon dioxide emissions. Wang et al. (2013) studied the design problem of remanufacturing closed-loop supply chain in the context of low-carbon economy. Lah (2015) believed that policies such as fuel pricing, differential taxes, vehicle standards, and supply model selection can minimize the reduction of greenhouse gas emissions in the logistics and transportation sectors. Taptich et al. (2015) studied the impact of two freight modes (truck and rail multimodal transport) for two representative goods (meat/seafood and paper products). Caiado et al. (2017) considered Brazil's reverse logistics market and found that it still had no legal support. No organization controls and audits the market and government support is lacking, thus, the logistics performance in electronic product recycling is dire. He et al. (2017) selected eight representative and leading logistics enterprises in the western region of China for a case study and found that the obstacles affecting the development of low-carbon logistics mainly include lacking low-carbon awareness, inconsistent and incomplete policies and regulations, inadequate qualified logistics professionals, unreasonable infrastructure and facilities, low logistics operation management efficiency, and transportation mode confusion. The existing literature reveals that foreign developed countries are relatively mature with less environmental pollution due to the early development of the logistics industry. By contrast, China and other developing countries have caused certain environmental pollution due to the lack of advanced logistics concepts and backward logistics equipment. However, developing countries such as China have effectively reduced environmental pollutant emissions and protected the environment by developing low-carbon logistics. Summarizing the environmental pollution caused by China's current logistics industry, measuring the low-carbon logistics efficiency of different provinces, and proposing improvement measures for the corresponding low-carbon inefficient provinces have a positive reference value for improving China's overall low-carbon logistics efficiency.

STATUS OF ENVIRONMENTAL POLLUTION IN CHINA'S LOGISTICS INDUSTRY

The huge logistics market of China and the relatively large profit of the logistics industry have attracted a substantial amount of investment and attention from all levels of government. Many large and small logistics companies have emerged everywhere, some of which are standardized, but others have only changed their names. They have the knowledge, talent, and strength to carry out logistics system planning. That unreasonable transportation exists during operation is inevitable. The emergence of a large number of unreasonable transportation wastes manpower, material resources, financial resources, and time. In addition, road

Fig. 1: Total social logistics in China from 2010 to 2017.
(Data from China Federation of Logistics and Purchasing. http://www.chinawuliu.com.cn/)

freight has always occupied the main transportation position of China's logistics industry with high proportions, as shown in Fig. 2. A large number of freight cars aggravate the burden on existing transportation facilities, which resulting in a large amount of air and noise pollution. Additional highways and expressways occupy the original farmland and green space, and they are detrimental for pollution control and environmental protection. With the continuous development of the logistics industry, traffic pollution has become one of the most serious urban environmental problems. Air pollution, noise pollution, visual pollution, traffic congestion, and energy consumption are all undesirable by-products of logistics and transportation.

Air pollution: Spatial displacement of goods in logistics is mainly through transportation methods such as trucks. The number of trucks have been rising every year, as shown in Fig. 3. However, the exhaust gas emitted by vehicles burning gasoline and diesel is the most harmful to the environment. The gas contains carbon monoxide, hydrocarbons, and particulate matter emitted by diesel engines, which directly pollutes the environment. Acid rain is formed by the combination of carbon dioxide and methane emitted from automobile exhausts with water in the atmosphere. Acid rain can cause secondary pollution of the air, thus polluting a wide range of animals and plants and producing photochemical smog. As the roads become developed, the number of vehicles engaged in freight transportation increases, and the photosynthetic smog formed by the exhaust gas after the sun illuminates will pollute the urban air for a long time. Discarded motor and diesel oil often infiltrate into the soil and water, which will inevitably cause environmental pollution.

Water pollution: The logistics industry has a large number of vehicles, and the wastewater generated by the vehicles during transportation pollutes the environment through the surface and road runoff of the road construction site. Pollution is caused by vehicle exhaust, vehicle component wear, road wear, spoilage, atmospheric dust, and toxic and hazardous transport accidents. The throwing of the goods, falling of particles in the automobile exhaust, dripping of the automobile fuel, and the wear of the tire on the road surface during transportation of goods are harmful. All of those harmful substances are carried into the water body or farmland when the precipitation forms surface runoff.

Noise pollution: Transportation vehicles in the logistics industry produce noise that can damage the environment. Due to the development of the road transport network, almost every corner is now affected by the noise pollution caused by road transport. As with the harms caused by the exhaust of transport vehicles, the noise generated also destroys the living environment of human beings and seriously affects people's health. Most transportation companies rely on overload transportation to save costs and improve economic efficiency. Individual vehicles are particularly serious, which not only causes frequent accidents, but also greatly shortens the service life of vehicles. In addition, overloading increases vehicle exhaust emissions and exhaust gas concentration due to the thick smoke from the exhaust of those freight cars.

CALCULATION OF CHINA'S LOW-CARBON LOGISTICS EFFICIENCY

Introduction to the DEA-BCC model: DEA is an important analytical method for calculating "relative efficiency". This method retains the input or output of the decision-making unit (DMU) and determines the optimal input-output scheme

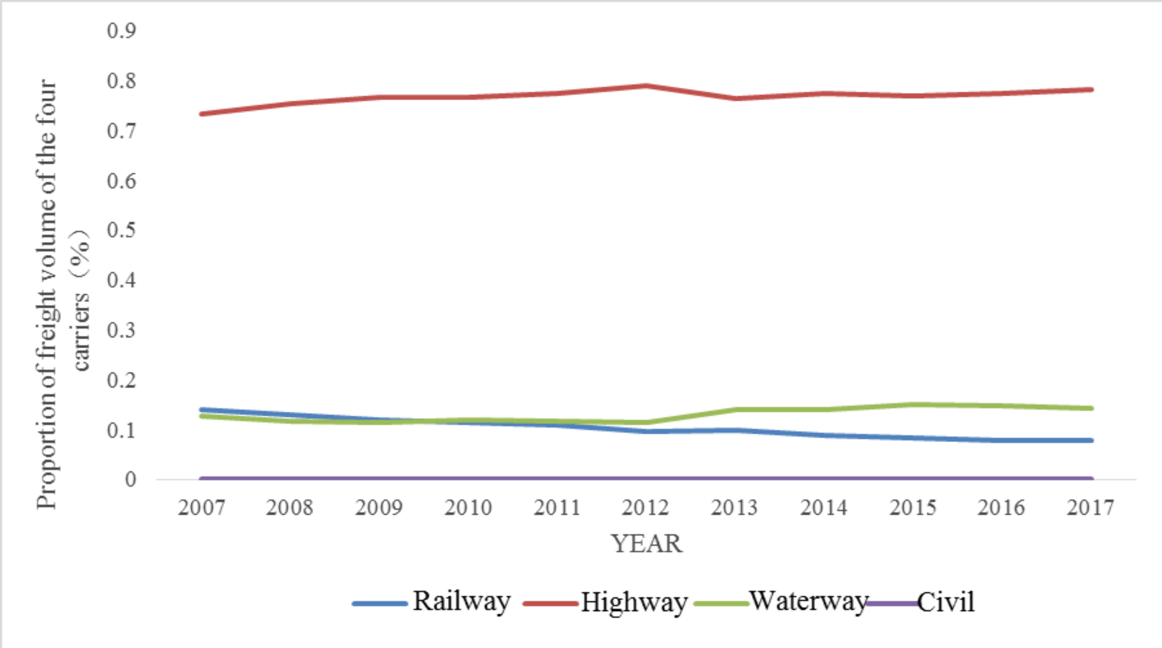

Fig. 2: The proportion of freight volume of the four major modes of transport in 2007-2017.
(Data from the National Statistical Database of the National Bureau of Statistics of the People's Republic of China. http://data.stats.gov.cn/)

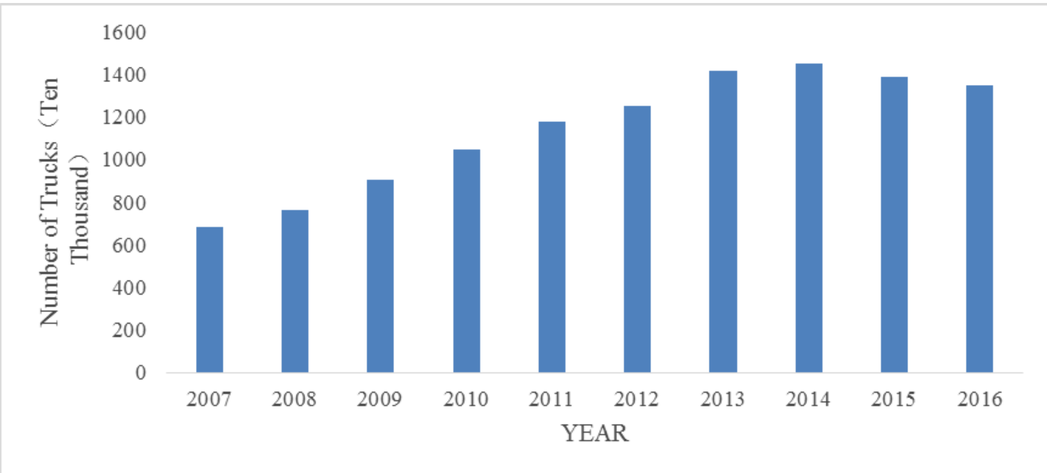

Fig. 3: Number of trucks in China (2007-2016). (Data from China Statistical Yearbook (2008-2017))

of the DMU through mathematical planning and statistical data. From this, the validity is evaluated on the basis of actual input and output.

Assuming that there are n decision units DMU with m input variables and s output variables in the DEA-BCC model, the input and output vectors of the j th decision unit D_j are:

$x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T$ and

$y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T, (j = 1, 2, \cdots, n).$

As there are more than one input and output indicators, they cannot be simply added for comparison. Therefore, weighting numbers should be introduced, and input and output indicators should be weighted to integrate input and output indicators. The weight of the input indicator is defined as v, and the weight of the output indicator is defined as u. The weight vectors of the input and output are

$v_j = (v_1, v_2, \cdots, v_m)^T$ and $u_j = (u_1, u_2, \cdots, u_s)^T$. We define a function as follows:

$$h_j = \frac{u^T y_i}{v^T x_j} = \frac{\sum_{k=1}^{s} u_k y_{kj}}{\sum_{i=1}^{m} v_i x_{ij}} \quad ...(1)$$

This function of (1) is defined as the efficiency evaluation index of the *j* th decision unit *Dj*. Each of them is no more than 1, that is, max $hj \leq 1$ If hk = 1, then the *k* th decision unit is the most efficient for other decision units, or the decision unit is relatively efficient (compared to other decision units of the study).

We can judge whether *Dj* is valid by changing the weights *v* and *u* to observe the maximum value of *hj* at each change, so a CCR model should be constructed.

$$\max h_{j0} = \frac{\sum_{k=1}^{s} u_k y_{kj0}}{\sum_{i=1}^{m} v_i x_{ij0}}$$

$$s.t. \quad \frac{\sum_{k=1}^{s} u_k y_{kj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad u \geq 0, \quad v \geq 0 \quad ...(2)$$

Equation (2) is a conditional constraint problem that requires a Charnes-Cooper change so that the above problem can be changed into a linear programming problem. The linear programming model is as follows:

$$\max h_{j0} = \mu^T y_0$$

$$s.t.\begin{cases} \omega^T x_j - \mu^T y_j \geq 0 \\ \omega^T x_0 = 1 \\ \omega \geq 0, \quad \mu \geq 0 \end{cases} \quad ...(3)$$

The above is to transform a complex nonlinear problem into a linear problem. The effectiveness of a DMU will be evaluated through the optimal solution of the linear problem. The efficiency obtained by this method is comparative to that of other DMUs with relative effectiveness rather than absolute validity. Therefore, establishing an even programming, expressed as follows, is necessary.

$$\min \theta$$

$$s.t.\begin{cases} \sum_{j=1}^{n} \lambda_j x_j \leq \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j \leq \theta y_0 \\ \lambda_j \geq 0, \quad j = 1,\ 2,\ \cdots,\ n \\ \theta \text{ Absence of Restriction} \end{cases} \quad ...(4)$$

To further facilitate the study, we must define a slack variable s^+ and a surplus variable s^- so that Equation (4) can become an equation problem. After adding two variables, the above inequality changes as follows:

$$\min \theta$$

$$s.t.\begin{cases} \sum_{j=1}^{n} \lambda_j x_j + s^+ = \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^- = \theta y_0 \\ \lambda_j \geq 0, \quad j = 1,\ 2,\ \cdots,\ n \\ \theta \text{ Absence of Restriction}, \quad s^+ \geq 0, \quad s^- \geq 0 \end{cases} \quad ...(5)$$

Considering that the scientific and technological input and output efficiency of Chinese universities are studied through review of literature and judgments of common sense, they are different from the returns to scale. Therefore, the variable returns to scale should be the premise of assumptions. Under this premise, evaluating the effectiveness of a DMU is actually a self-evaluation of a comprehensive efficiency (TE), which can be subdivided into two parts, namely, pure technical efficiency (PTE) and scale efficiency (SE).

Both (3) and (5) are linear problems with feasible and optimal solutions. Assuming that the optimal solutions for these two equations are h_{i0}^* and, θ^* due to duality, $h_{i0}^* = \theta^*$.

If, $\theta^*=1$, $s^{*\ +}=0$ and $s^{*\ -}=0$, then the DMU is considered valid for DEA, with optimal technical and scale efficiency. If, *θ*=1, βυτ* at least one input or output is greater than 0, then the DMU is valid for weak DEA, and the technical and scale efficiency are optimal at different times. If *θ** <1, then the DMU is not valid for non-DEA, and neither the technical nor scale efficiency is optimal.

Data sources and processing instructions: To empirically study the low-carbon logistics efficiency of 30 provinces (autonomous regions and municipalities) in China in 2016 (the Tibet Autonomous Region was excluded due to incomplete date), five input and two output indicators are selected. Input indicators are number of employees in the logistics industry, new fixed assets, length of logistics routes, energy equivalents, and carbon emissions in the logistics industry. Output indicators are logistics volume and GDP of logistics. The data on the number of employees in the logistics industry, new fixed assets in the logistics industry, and length of the logistics industry transportation routes are from the statistical data of the transportation, warehousing, and postal industries in the China Statistical Yearbook (2017). The energy consumption equivalent data of the logistics industry are converted from the energy consumption statistics of standard coal, which is from the Statistical Yearbooks of provinces and municipalities in 2016. The carbon emissions of the logistics industry of provinces are from the China Energy Statistical Yearbook (2017) and the China Statistical Yearbook (2017). The data are obtained by collecting the terminal energy consumption data of raw materials such as raw coal and fuel oil in the logistics industry

Table 1: Logistics efficiency of 30 provinces (autonomous regions and municipalities) in China.

DMU	TE	PTE	SE	DMU	TE	PTE	SE
Beijing	1.000	1.000	1.000	Hubei	0.645	0.654	0.986
Tianjin	1.000	1.000	1.000	Hunan	0.649	0.685	0.947
Hebei	0.971	0.985	0.986	Guangdong	0.979	0.985	0.994
Shanxi	0.843	0.865	0.974	Guangxi	0.815	0.845	0.965
Inner Mongolia	0.970	0.986	0.984	Hainan	0.722	0.958	0.754
Liaoning	0.986	0.999	0.987	Chongqing	0.599	0.685	0.874
Jilin	0.607	0.714	0.850	Sichuan	0.815	0.854	0.954
Heilongjiang	0.815	0.845	0.964	Guizhou	0.815	0.965	0.845
Shanghai	0.956	1.000	0.956	Yunnan	0.725	0.841	0.862
Jiangsu	1.000	1.000	1.000	Henan	0.846	0.854	0.991
Zhejiang	1.000	1.000	1.000	Shanxi	0.796	0.842	0.945
Anhui	1.000	1.000	1.000	Gansu	0.755	0.864	0.874
Fujian	0.940	0.974	0.965	Qinghai	0.686	0.812	0.845
Jiangxi	0.986	1.000	0.986	Ningxia	0.615	0.784	0.784
Shandong	1.000	1.000	1.000	Xinjiang	0.719	0.854	0.842

and referring to the carbon emission coefficient table of the Intergovernmental Panel on Climate Change (IPCC) in 2006. The information of the table is equivalent to the carbon emissions of the logistics industries of the provinces. The volume of logistics in the output index and the GDP of the logistics industry are from the China Statistical Yearbook (2017). The GDP index of the logistics industry reflects not only the economic development of the logistics industry in the region, but also the development capacity of the industry in 2016.

Analysis of settlement results: DEAP 2.1 software is adopted to calculate the processed data based on the VRS-based DEA-BCC model (input-oriented model is selected). The comprehensive efficiency, pure technical efficiency, and scale efficiency values of low-carbon logistics in 30 provinces in China are obtained. Table 1 presents the specific processing results.

1. Twenty-four provinces have non-DEA efficiency in terms of China's low-carbon logistics efficiency. The comprehensive efficiency value of low-carbon logistics in Beijing, Tianjin, Jiangsu, Zhejiang, Anhui, and Shandong is 1, reaching validity of DEA. This value indicates that the ratio of input and output of these provinces in the development of low-carbon logistics is optimal with the most efficient use of input resources and maximum output. However, these regions only account for 20% of China, implying that China's overall low-carbon logistics efficiency is low.
2. Thirteen provinces have relatively high DEA efficiency in low-carbon logistics efficiency values (efficiency values between 0.8 and 1.0), namely, Hebei, Shanxi, Inner Mongolia, Liaoning, Guangdong, Guangxi, Sichuan, Guizhou, Heilongjiang, Shanghai, Henan, Fujian, and Jiangxi, accounting for 43.33%. The low-carbon logistics efficiency value of these regions does not reach the best, indicating that its high output is mainly from high input, not high technical efficiency. Therefore, low-carbon logistics efficiency can be improved by enhancing the efficiency of pure technology. At the same time, these regions have not reached the optimal production scale. In developing low-carbon logistics, these regions should continuously adjust their scale while improving the pure technical efficiency of their low-carbon logistics.
3. Eleven provinces (have low low-carbon logistics efficiency (efficiency value below 0.8), accounting for 36.67%, of which Ningxia has the lowest comprehensive efficiency level with only 0.615. These provinces are located in the central and western regions of China. The low-carbon logistics efficiency in these regions are significantly lower compared with that of the eastern regions, which are strong in economic strength. The economic development in the central and western regions is lagging behind due to geographical constraints. The infrastructure (e.g., transportation) and people's living standards are low, resulting in insufficient cultivation and absorption of talents and introduction of funds and new technologies.

MEASURES TO DEVELOP LOW-CARBON LOGISTICS

Improving relevant regulations of low-carbon logistics: To implement effective incentives, the government should establish a complete carbon trading system and a professional carbon trading registration management department. With this system and department, the government can obtain complete and open registration information, establish a voluntary carbon trading market, encourage logistics enterprises to actively participate in transactions, and improve the market for carbon trading, thus providing facilities for trading. The unified norms of policies and regulations should also be effectively implemented by logistics enterprises. In order to achieve this, the government must actively promote the study of relevant policies and regulations by logistics enterprises and organize specialized training courses and study groups for training accounting methods and quota allocation of different types of logistics enterprises.

Establishing a carbon trading credit registration system: The government can offer preferential financial policies in terms of investment and taxation to logistics enterprises with good credit status and prioritize them in every awards event. The government can also provide these enterprises with free publicity in official activities and publish relevant corporate social responsibility rankings regularly with both internal and external incentives. Logistics enterprises with poor credit status can convert the non-standard carbon emission quota into a mandatory green area according to certain indicators to effectively reduce the harm caused by excessive carbon emission.

Establishing a sound logistics recovery system: The government should stipulate standardized recycling methods for various types of wastes in the form of relatively complete laws and regulations and set up special functional departments to manage them. The first step is to complete the waste recycling facilities and set up different types of waste recycling devices in different areas. Second, the use of different recycling devices should be publicized in the community to let everyone know how to distinguish them. Finally, the waste from different recycling devices should be carried out professionally to effectively use resources and reduce pollution.

Exploring low-carbon logistics education actively: The government should actively organize relevant departments to carry out training courses so that business managers and university teachers can become familiar with the current situation as soon as possible. With raised awareness, business managers and university teachers can transform the current latest theories into teaching and practical applications. The public awareness of low-carbon logistics can be strengthened through public resources such as television, newspapers, and street advertisements. The gradual registration of individuals' low-carbon credits can also be implemented. Corporate managers should include low-carbon environmental protection as important considerations in their daily operations. In selecting logistics solutions, low-carbon and environmental protection plans should be considered comprehensively.

Developing low-carbon logistics technology vigorously: Technological innovation is the core for promoting the application of energy-saving and emission reduction technologies in low-carbon development. Comprehensive measures should be taken to create a market environment for developing low-carbon logistics. These measures may include encouraging the promotion of energy-efficient and low-emission technologies and actively developing clean, renewable and new energy to provide strong technical support for low-carbon transformation. In addition, "low-carbon transportation" should be vigorously developed, the use of energy-saving and new energy vehicles should be promoted, and the river-sea combined transport of goods should be implemented to further realize the intermodal mode of high-speed rail and port. Moreover, RFID technology should be applied to the construction of green intelligent transportation systems. Building a smart transportation system by the Internet of Things to collect and analyse comprehensive traffic information, and conduct traffic control according to road congestion conditions, so that the traffic flow on the road network can reach an optimal state, so as to improve traffic congestion and reduce vehicle pollution.

CONCLUSION

As one of China's top ten revitalizing industries, the logistics industry has developed rapidly. However, air, water, and noise pollution has occurred as well. The development of low-carbon logistics can effectively meet energy conservation and emission reduction, thereby reducing environmental pollution and achieving coordinated development of the logistics industry and ecological environment. The causes of environmental pollution caused by the Chinese logistics industry were summarized, and the DEA-BCC model was used to calculate the low-carbon logistics efficiency of 30 provinces in 2016. The results show that air, water and noise are polluted by the high volume of road transport and freight of China's logistics industry; the efficiency of low-carbon logistics in China as a whole is still low; the comprehensive efficiency value of low-carbon logistics is 1 in only 20% of provinces. The provinces with low comprehensive efficiency of low-carbon logistics (0.8) account for 36.67%, all of which located in the central and western regions of China. Such problems can be solved by improving the relevant regulations of low-carbon logistics, establishing a carbon trading credit registration system, building a sound logistics recycling system, exploring low-carbon logistics education actively, and vigorously developing low-carbon logistics technologies. In-depth research on the calculation of carbon emissions from logistics, influencing factors of low-carbon logistics, innovation of low-carbon logistics development model, and implementation mechanism and countermeasures for developing low-carbon logistics can be conducted in the future.

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