Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

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

Vol. 17 | No. 1 | pp. 77-86 | 2018

Original Research Paper | Open Access

Areal Variation Measurement and Influencing Factor Decomposition of Carbon Emissions of Regional Logistics Ecosystems

Jie Wu*(**), Lingyun Zhou† and Yachao Wu****

*Department of Business Management, Kunshan Dengyun College of Science and Technology, Suzhou 215300, China

**Key Laboratory for Traffic and Transportation Security of Jiangsu Province, Huaiyin Institute of Technology, Huaian 223003, China

†Corresponding author: Lingyun Zhou

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

Received: 15-12-2017
Accepted: 16-01-2018

Key Words:
Regional logistics ecosystem
Carbon emission
Areal variation
Factor decomposition

ABSTRACT

Carbon emissions significantly affect the sustainable development of regional logistics ecosystems. However, the existing studies on logistics carbon emissions seldom consider the spatial inequality characteristic. A comprehensive approach to analyse the areal variations and the influencing factors of carbon emissions of regional logistics ecosystems accurately, was proposed in this study. The carbon emissions of regional logistics ecosystems were initially discussed and their areal variations were measured using Theil index model. Then, the key influencing factors of carbon emission change of regional logistics ecosystems, as well as the effects of these influencing factors were analysed. Finally, an empirical analysis was conducted considering Jiangsu province in China as an example. Results demonstrate the following: (1) The areal variations of carbon emissions of regional logistics ecosystems between regions and within regions can be measured objectively and scientifically with Theil index model, and the areal variation changes in carbon emissions can be accurately reflected. (2) The influencing factors of carbon emissions of regional logistics ecosystems can be classified into three factors, namely, energy structure, economic scale, and industrial structure, by using the logarithmic mean Divisia index decomposition approach. Moreover, the contributions of influencing factors to the carbon emission changes can be identified quantitatively. (3) Results of the empirical analysis show that the energy structure and economic scale in Jiangsu province positively affect the carbon emissions of regional logistics ecosystems. However, the industrial structure plays an adverse role. The study provides a new decision-making method to analyse quantitatively the areal variations in carbon emissions of regional logistics ecosystems, which can be used as a reference when designing differentiated measures and policies for low-carbon logistics development in different regions.

INTRODUCTION

All countries worldwide realize the importance of developing low-carbon economy, given the existence of global environmental problems. Today, developing low-carbon economy has attracted increasing attention from enterprises and organizations throughout the world (Matthews et al. 2008). The development of low-carbon economy should be greatly supported by modern logistics industry, given the changing climate and the increasing energy consumption. That is, modern logistics industry definitely plays an important role in low-carbon economy. Modern logistics industry can save energy and reduce emissions, and it is useful for the development of low-carbon economy.

With the rapid development of the economy of China, the logistics industry has become crucial, greatly affecting the structure adjustment, the transformation of development pattern, and the increase in production and domestic demand. At present, the logistics industry has become the fundamental and leading industry of the national economy. Relevant statistics in 2016 shows that the total sales volume by the logistics industry in China was as much as 3,460 billion USD, with a year-on-year growth of 6%; the total logistics fee was approximately 1,660 billion USD, with a year-on-year growth of 3%; the ratio between logistics fee and gross domestic product (GDP) was decreased to 15%. However, in developed countries, the ratio between logistics fee and GDP was approximately 8%-9%. In America, the logistics cost was approximately 8% of its GDP, whereas in Japan, the logistics cost was approximately 11% of its GDP (He 2017). These figures show that the logistics industry in China is developing and that the quality of logistics operation and its contributions stably increased. However, the logistics industry in China still experiences an extensive development and scale expansion, the performances of which in terms of socialization, integration, and professionalization are at a low level. At present, the logistics industry has caused great waste of resources and high energy consumption because of the disadvantages, such as irrational industrial structure, decentralized distribution of logistics facilities, low efficient mode of logistics operation and supply chain management, and the lagging application of modern logistics technological devices. Therefore, carbon emissions cannot be reduced, which adversely affects the sustainable development of the logistics industry. The regional logistics industry expands immediately, given the rapid development in the regional economy integration. Therefore, regional logistics activities are widely and frequently performed, thereby producing environmental pollution increasingly. In fact, regional logistics industry has become the major sector that consumes energy and emits carbon (Liu et al. 2016). Thus, the logistics industry should be immediately developed into a low-carbon industry.

At present, China faces a great shortage in energy, climate change, and serious environmental pollution. Thus, ideologies, such as developing green and low-carbon economy and sustainable development, as well as constructing the regional logistics ecosystems, have been emphasized in theoretical and practical research. However, the existing theoretical studies focus on the calculation of carbon emissions, control measures, and policies used by the national logistics ecosystem, regional logistics ecosystem, or enterprise supply chain system. Nevertheless, energy consumption, economic structure, and logistics activity are different between regions; thus, the carbon emissions of the logistics industry and their influencing factors also vary in each region. The existing studies seldom investigate the areal variation and influencing factors of carbon emissions of the logistics industry. Thus, the areal variations and influencing factors of carbon emissions of regional logistics ecosystems are investigated and analysed in this study. The present method is useful and meaningful to design countermeasures and policies for developing low-carbon logistics.

STATE OF THE ART

Few research achievements in the field of carbon emissions of the logistics industry are available. Some scholars conducted studies that are mainly focused on the computation, influencing factor, and control measures related to the carbon emissions of the logistics industry.

Logistics industry is an emerging industry, which has developed in recent years. Thus, the statistics data on energy consumption by the logistics industry in many countries are not available. The study on the computation of carbon emissions of the logistics industry still focuses on the quantitative evaluation of carbon emissions by traffic and transport. In 1996, McKinnon & Wood designed a model framework to quantify the CO_2 emission of the logistics industry. In this model framework, four factors affect the CO_2 emission, namely, structure (the position of warehouses and logistics volume), commerce (distribution plan and procurement plan made by the enterprise), operation (product circulation, loading and unloading, and transport of products), and traffic resource (the selection of transport tools and transport modes) (McKinnon & Woodburn 1996). McKinnon and Piecyk amended the measurement scope of carbon emissions, traditional statistic methods, coordination between the forwarding agent and transport department, and application of transport data, according to the actual situation in England (McKinnon & Piecyk 2009). The studies conducted subsequently followed the trace of carbon emissions of the logistics industry and established an evaluation analysis model, by which they analysed the relationship between road transportation and carbon emissions. Meanwhile, they predicted and simulated the carbon emissions of road transport in three scenarios (i.e., normal, pessimistic, and optimistic scenarios) in 2020 by group discussion and Delphi method. Their research provided reference for carbon emission measurement of transport industry. The evaluation analysis model can quantify the road transport demands of the logistics industry, by which the carbon emissions of road transport can be efficiently estimated (Piecyk & McKinnon 2010). Liu et al. (2015) proposed a model to calculate the carbon emissions of coal mining transportation and obtained the inequalities of carbon emissions by analysing the transportation by trucks and belt conveyors used by outdoor coal mining. Some scholars conducted a research by dividing China into 30 provinces and cities, and estimated the quantity of carbon emissions by using the data related to energy consumption of the transport industry (Zhang & Cai 2014, Jin et al. 2015, Zhou et al. 2015). Numerous scholars from China and other countries studied the carbon emission inequality of the logistics industry via different theories and methods. However, only few analyses and studies focus on the carbon emissions of the regional logistics industry. Different regions develop varied logistics industries, whose energy structures and carbon emissions are entirely different from one another. Therefore, the logistics carbon emissions between regions, as well as the carbon emissions within regions, should be compared. Then, some references for designing policies and measures to reduce carbon emissions can be provided.

The influencing factors of carbon emissions should be identified to provide emission reduction proposals. The influencing factors of carbon emissions of the logistics industry are studied from several views, including the regional government management, enterprise logistics management, and perfection of supply chain management to design measures and policies for emission reduction. Sundarakani et al.

(2010) established a 3D footprint model to analyse the carbon emissions of enterprise supply chain. Then, by a simplified case, verification was performed. Thus, by generally designing the supply chain, carbon emissions could be reduced by appropriately controlling the low carbon at an adjustable period of supply chain. When designing the supply chain network for enterprises, Chaabane et al. (2012) proposed the sensitization suffered by carbon emissions and indicated that the strategic planning of supply chain should consider the environmental regulatory factors in two aspects, namely, external and internal. From different views, Harris et al. (2011) studied the construction of supply chain under the ideology of low-carbon sustainable development. Under environmental regulatory conditions, the low-carbon target of logistics supply chain and the profit target set by an enterprise are not conflicting. Some scholars analysed the origin of carbon emissions of the logistics supply chain (Ageron et al. 2012, Kristina et al. 2015, Benjaafar et al. 2013, Luo et al. 2016). Then, they proposed measures and suggestions to reduce carbon emissions from enterprise logistics and supply chain. Tacken et al. (2014) studied the motivation (by individuals who are involved in the logistics industry in Germany) in reducing CO_2 emission; they proposed the framework for low-carbon supply chain management. Most of these studies started from the view of supply chain and analysed the influencing factors and control measures of logistics carbon emissions. Therefore, studies on the factors affecting the carbon emissions of regional logistics from the view of spatial inequality are limited.

In the study, the areal variations of the carbon emissions of regional logistics ecosystems are investigated and analysed. Then, the factors affecting the carbon emissions of regional logistics ecosystems are identified by using logarithmic mean Divisia index (LMDI) model, and the action mechanism and influential effect of these factors are explored.

METHODOLOGY

Inequality measurement model for carbon emissions of regional logistics ecosystems: Regional logistics ecosystem is an open system away from an equilibrium status. Therefore, the internal subsystems and elements of transportation, warehousing, distribution, circulation, processing, handling, packaging, and information service are unbalanced. Each subsystem and element, as well as all types of resources, are distributed unevenly in each internal space. At the same time, the low-carbon logistics technology and control measures implemented in each region are also different. All these factors lead to significant areal variations of carbon emissions. Theil index, which measures relative differences among variables, has developed into an important method for measuring the development inequalities. Its basic concept was presented by Shannon and Wiener based on the concept of entropy in information theory. The significant advantage of the index method is that it can divide the overall variation into two parts, that is, the variation within regions and the variation between regions. Thus, contributions from them to the overall difference can be observed and measured well (He et al. 2015). When a Theil index is large, the areal variation is also large, and vice versa. Theil index method can be used for a quantitative analysis of the variation and change of carbon emissions of regional logistics ecosystems. The carbon emission Theil index model of regional logistics ecosystems is established based on analysing the different characteristics of logistics carbon emissions. The calculation formulas are as follows:

$$T_B = \sum_j \left(\frac{C_j}{C}\right) \ln \frac{C_j / C}{P_j / P} \qquad ...(1)$$

$$T_{w_j} = \sum_i \left(\frac{C_{ji}}{C_j}\right) \ln \frac{C_{ji} / C_j}{P_{ji} / P_j} \qquad ...(2)$$

$$T_w = \sum_j \frac{C_j}{C} T_{w_j} \qquad ...(3)$$

$$T = T_B + T_w \qquad ...(4)$$

Where, C denotes the carbon dioxide discharge, j represents the i region, represents the city in the region, T_B is the inter-regional Theil index, Tw_j is the Theil index of region j, T_w is the intra-regional Theil index, T is the overall Theil index, and P is the gross value of the production of regional logistics industry. Usually, the Theil index is between 0 and 1. When the index is large, the areal variation is also large, and vice versa. The intra-regional contribution rate is the ratio between the intra-regional Theil index and the overall Theil index. The intra-regional contribution rate is the ratio between the intra-regional Theil index and the overall Theil index.

Factor decomposition of carbon emissions of regional logistics ecosystems: The carbon emission levels of regional logistics ecosystems are different, which can be mainly attributed to the differences in influencing factors. Therefore, the corresponding quantitative factor decomposition method should be considered in the research on the variation characteristics and the mechanism of action of the main influencing factors of carbon emissions of regional logistics ecosystems. Currently, metrological regression, structural analysis method, and index decomposition method are often used to analyse the influence on carbon emissions caused by change of factors. The research on factor decomposition method has become a topic of interest in international energy studies. It is also a widely accepted research method for energy issues. LMDI factor decomposition method is widely used for energy-related research because of its complete decomposition with no residual error, strong adaptability, ease of explanation, consistency, and unique result of multiplicative and sum decompositions (Liu et al. 2015). LMDI method mainly considers time sequence data as the research object to investigate reasons and influencing factors for a variable to change in different periods of time.

The influencing factors of carbon emissions of regional logistics ecosystems can be identified, variable characteristics and main influencing factors can be studied, and a conclusion on mechanism of action, influence degree, and effect of each factor can be drawn by using the LMDI decomposition model. Logistic energy consumption composition, economic size, and industrial structure have a close inner link with logistics carbon emissions. Therefore, the influencing factors of carbon emissions of regional logistics ecosystems are divided into energy structure, economic-scale, and industrial structure effects. The decomposition process is shown as follows:

$$ES_{effect} = \sum_j \left[\left(C_j^t - C_j^0\right)/\left(\ln C_j^t - \ln C_j^0\right)\right]\ln\left(ES_j^t / ES_j^0\right) \quad ...(5)$$

$$G_{effect} = \sum_j \left[\left(C_j^t - C_j^0\right)/\left(\ln C_j^t - \ln C_j^0\right)\right]\ln\left(G^t / G^0\right) \quad ...(6)$$

$$S_{effect} = \sum_j \left[\left(C_j^t - C_j^0\right)/\left(\ln C_j^t - \ln C_j^0\right)\right]\ln\left(S^t / S^0\right) \quad ...(7)$$

Where, ES_{effect} is the contribution value of the difference in energy structure to that in carbon emissions of regional logistics ecosystems; G_{effect} is the contribution value of the difference in economic scale to that in carbon emissions of regional logistics ecosystems; S_{effect} is the contribution value of the difference in industrial structure to that in carbon emissions of regional logistics ecosystems; C^t_j and C^o_j are the carbon emissions in period t and energy j in the base period, respectively; ES^t_j and ES^o_j are the energy structures in period t and energy j in the base period, respectively; G^t and G^o are the economic scales in period t and the base period region, respectively; and S^t and S^o are the regional logistic industrial structural ratios in period t and the base period region, respectively.

RESULT ANALYSIS AND DISCUSSION

In this study, regional logistics ecosystems of Jiangsu Province in China are selected and analysed as a case. Although Jiangsu province is an economically developed province in China, the imbalance in its economic development is relatively prominent. The economic development levels in South Jiangsu, Middle Jiangsu, and North Jiangsu present the characteristic of gradient development. Thus, logistics carbon emissions in Jiangsu province also present the evident areal variation characteristic.

Calculation of Carbon Emissions in Sample Regions

The boundary of the regional logistics industry is indistinct, and a special statistical yearbook is unavailable. Transportation, warehousing, and postal service are important components of the logistics industry. Therefore, their carbon emissions represent the main carbon emissions of regional logistics ecosystems. The statistical data of the energy consumption in Jiangsu Energy Statistical Yearbook show that the energy consumption values of regional logistics ecosystems in Jiangsu province are concluded after being converted to standard coal. The details are given in Table 1.

The National Development and Reform Commission suggests that the carbon content of coal should be valued at 67% according to the coal utilization rate of China. That is, 1 kg of standard coal will emit 0.67 kg of carbon after combustion, representing a total of 2.46 kg of carbon dioxide. The carbon emissions of regional logistics ecosystems in Jiangsu are calculated based on that standard. The specific results are presented in Table 2.

The regional logistics carbon emissions in South Jiangsu had always been ahead of Middle Jiangsu and North Jiangsu from 2007 to 2014. The logistics carbon emissions in the three regions had always been presented in a growing status. South Jiangsu had the largest total amount of the logistics carbon emissions with a relatively faster average growth rate. Only three cities in Middle Jiangsu had the smallest regional logistic carbon emissions, with a slow rising status. The rising trend of the logistics carbon emissions in North Jiangsu had been relatively evident from 2010 to 2014.

Variation Measurement and Analysis on Carbon Emissions in Sample Regions

The Theil indexes of carbon emissions of regional logistics ecosystems in Jiangsu and the regional decomposition results from 2011 to 2014 are obtained according to Formulas (1)-(4). The specific results are given in Table 3.

The overall Theil index of carbon emissions of regional logistics ecosystems in Jiangsu peaked at 0.394 in 2009, and the lowest was at 0.340 in 2007. The Theil indexes within regions were generally higher than those between regions. Therefore, the variation within regions were the main reason for the variant status presented in carbon emissions of regional logistics ecosystems in Jiangsu in the past.

The fluctuation of the Theil indexes within regions on carbon emissions of regional logistics ecosystems in Jiangsu was considerably evident compared with the Theil indexes

Table 1: Energy consumption of Jiangsu logistics ecosystem (unit: ten thousand tons of standard coal).

		2007	2008	2009	2010	2011	2012	2013	2014
South Jiangsu	Nanking	142.47	184.33	183.45	199.52	213.89	231.19	238.08	253.07
	Wuxi	126.30	130.33	126.36	134.43	150.99	159.25	172.62	184.00
	Changzhou	91.80	105.85	96.55	113.38	124.08	139.24	142.09	159.26
	Suzhou	184.43	205.62	213.70	248.99	279.82	305.81	320.44	338.74
	Zhenjiang	56.29	66.06	72.64	82.62	83.80	80.42	94.65	109.57
Middle Jiangsu	Nantong	105.43	114.89	129.00	164.03	172.22	187.13	199.65	221.09
	Yangzhou	69.24	73.01	68.00	71.26	82.25	95.39	106.69	118.07
	Taizhou	44.80	50.04	56.38	62.00	70.59	87.02	97.47	100.31
North Jiangsu	Xuzhou	105.91	122.89	128.66	147.36	163.09	175.33	184.08	208.66
	Lianyungang	68.02	89.71	83.52	91.66	103.45	110.79	124.94	133.74
	Huai'an	45.63	51.15	68.80	76.12	85.58	91.56	96.13	107.26
	Yancheng	76.93	82.98	110.70	101.35	116.88	137.21	152.54	160.87
	Suqian	47.74	45.87	68.42	70.70	76.76	71.05	68.04	74.24

Table 2: Carbon dioxide emissions of Jiangsu logistics ecosystem (unit: ten thousand tons).

Year	South Jiangsu	Middle Jiangsu	North Jiangsu	Total
2007	1,479.17	539.90	846.78	2,865.85
2008	1,702.77	585.36	965.81	3,253.94
2009	1,704.02	623.32	1,131.83	3,459.17
2010	1,916.20	731.33	1,198.47	3,846.00
2011	2,097.35	799.65	1,342.58	4,239.58
2012	2,253.15	909.06	1,441.42	4,603.63
2013	2,380.99	993.38	1,539.51	4,910.88

between regions. A moderate increase had been observed from 2007 to 2009, and the index peaked at 0.353 in 2009. The Theil indexes between regions presented an unstable inequality. The Theil index had declined slowly from 2007 to 2008, during which the areal variations of logistics carbon emissions between regions had been constantly narrowing. The Theil indexes had gradually increased from 2008 to 2009 and then decreased again from 2009 to 2011. Since 2011, the fluctuation had been relatively small. From an overall perspective, the areal variations of carbon emissions of logistics ecosystems between regions in Jiangsu presented a relatively stable status in the past.

The Theil indexes of regional logistics carbon emissions in South Jiangsu, Middle Jiangsu, and North Jiangsu presented an alternative variation. South Jiangsu obtained its peak in 2008 and then attained a declining status, indicating that the variation in South Jiangsu had become small. In the same way, North Jiangsu obtained its peak in 2008, and since then, its fluctuation had been moderate, but presented a generally declining trend. The Theil indexes in Middle Jiangsu were the highest in 2010. From an overall perspective, the values of Theil indexes in North Jiangsu had always been in a leading position from 2007 to 2014, and the Middle Jiangsu had slightly lower results than that of South Jiangsu.

The contribution rates are given in Table 4. The intra-regional contribution rates of the Theil indexes within regions have always been in a high position from 2007 to 2014 with an average of 0.918, which was considerably larger than the inter-regional contribution rate of the Theil indexes between regions at 0.081. From the point of view of the region formation, the contribution rates of the Theil indexes in North Jiangsu were the largest with an average of 0.056, which is consistent with high Theil index values in North Jiangsu. The contribution rates of the Theil indexes in Middle Jiangsu were the lowest with an average of 0.027, which was consistent with low Theil indexes in Middle Jiangsu. The contribution rates of the Theil indexes in South Jiangsu were in the middle position with an average of 0.051. In terms of the variation trend, the fluctuation in North Jiangsu was relatively evident, whereas those in Middle and North Jiangsu were relatively moderate. The influence of Northern Jiangsu on the overall variation of logistics carbon emissions was higher than those of South and Middle Jiangsu.

Influencing Factors and Effects of Carbon Emissions on Sample Regions

Energy structure effect: The statistical data show that the energy consumption structure of regional logistics ecosystems in Jiangsu mainly includes gasoline and diesel, and the proportion of gasoline and diesel consumption increases year by year. The details are shown in Fig. 1. As an important sub-industry of modern logistics in Jiangsu, cargo transportation takes a large consumption of the direct use of petrol and diesel. In recent years, the clean energy consumption of liquefied petroleum gas and natural gas has a moderate improvement in the logistics industry, thereby reducing

Table 3: Theil index decompositions of carbon emissions of Jiangsu logistics ecosystems.

Year	Theil Indexes in South Jiangsu	Theil Indexes in Middle Jiangsu	Theil Indexes in North Jiangsu	Intra-regional Theil Indexes	Inter-regional Theil Indexes	Overall Theil Indexes
2007	0.015	0.008	0.024	0.311	0.028	0.340
2008	0.029	0.005	0.039	0.323	0.026	0.349
2009	0.026	0.007	0.019	0.353	0.041	0.394
2010	0.024	0.021	0.019	0.342	0.029	0.371
2011	0.018	0.014	0.018	0.338	0.030	0.368
2012	0.015	0.007	0.013	0.329	0.029	0.358
2013	0.012	0.005	0.018	0.325	0.029	0.355
2014	0.010	0.010	0.011	0.328	0.023	0.351

Table 4: Contribution rates of carbon emission Theil indexes of Jiangsu logistics ecosystems.

Year	Contribution Ratio in South Jiangsu	Contribution Ratio in Middle Jiangsu	Contribution Ratio in North Jiangsu	Intra-regional Contribution Ratio	Inter-regional Contribution Ratio
2007	0.044	0.024	0.071	0.915	0.082
2008	0.083	0.014	0.112	0.926	0.074
2009	0.066	0.018	0.048	0.896	0.104
2010	0.065	0.057	0.051	0.922	0.078
2011	0.049	0.038	0.049	0.918	0.082
2012	0.042	0.020	0.036	0.919	0.081
2013	0.034	0.014	0.051	0.915	0.082
2014	0.028	0.028	0.031	0.934	0.066

the carbon emissions in logistics.

Energy structure effect refers to the variation of the overall carbon emissions due to the proportion of different energies used in each year. The calculation results obtained according to formula (6) shows the changing values of carbon emissions of regional logistics ecosystems in Jiangsu due to energy structure effect. These results are shown in Fig. 2.

The energy structure effect was positive from 2007 to 2014 due to the variation of energy structure used by regional logistics ecosystem in Jiangsu province. From 2007 to 2008, the energy structure had reduced carbon emissions by 34,600 tons due to the low level of logistics development and low consumption of energy. However, from 2008 to 2014, the change in energy structure had caused carbon emissions to increase by 846,900 tons. From 2007 to 2014, the influence of energy structure effect on carbon emissions had been positive; thus, the energy structure should be further optimized.

Economic scale effect: Economic scale effect refers to the influence of the variation in GDP growth in Jiangsu Province on the carbon emissions of regional logistics ecosystem. The changing values of the carbon emissions of regional logistics ecosystem in Jiangsu province caused by the variation of the economic scale from 2007 to 2014 can be obtained according to Formula (6), as shown in Fig. 3. The economic growth in Jiangsu always had a positive influence on carbon emissions of its regional logistics ecosystem. The increment from 2009 to 2011 had been the largest at more than six million tons. During these eight years, the average annual increment had been 516.78 million tons.

Industrial structure effect refers to the influence of the proportional variation of the gross value of production of a logistics service industry that accounts for the GNP on carbon emissions of regional logistics ecosystems, which to a certain extent reflects the efficiency of logistics service to the national economy. The influence of the logistic industrial structure on the variation of carbon emissions of regional logistics ecosystems in Jiangsu from 2007 to 2014 can be obtained according to Formula (6), as shown in Fig. 4. From 2007 to 2014, the industrial structure effect had negatively influenced the carbon emissions of regional logistics ecosystem in Jiangsu province and had greatly contributed to the reduction in carbon emissions. During these eight years, a total of 2.8428 million tons of carbon had been reduced.

Countermeasures and Policy Suggestions

The government administrative departments and enterprises should timely formulate the appropriate corresponding logistics carbon emission reduction and logistics industry regulation policies according to the inequalities in the carbon emissions of logistics activities and the specific influ-

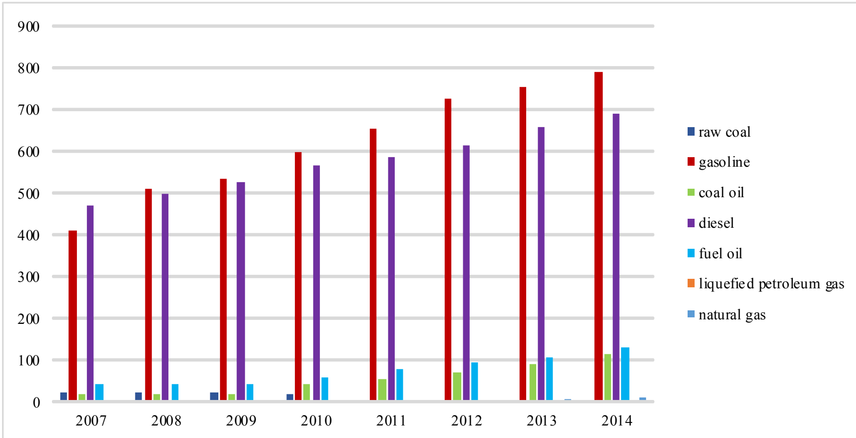

Fig. 1: Energy consumption structure of Jiangsu logistics ecosystem (unit: ten thousand tons of standard coal).

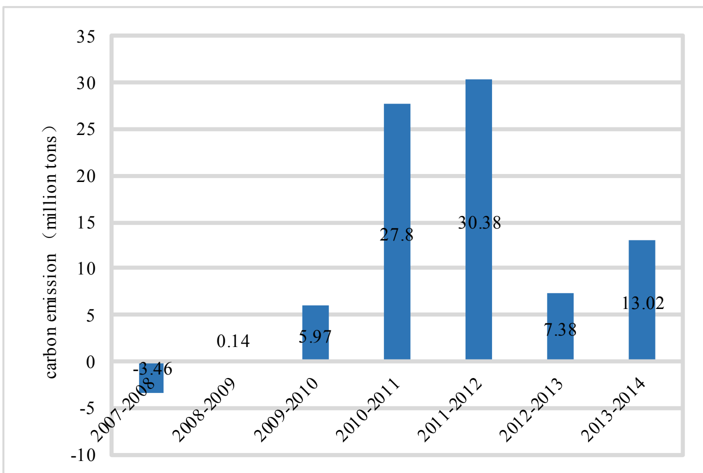

Fig. 2: Variation of carbon emissions of regional logistics ecosystems in Jiangsu due to energy structure.

encing factors in each region. The details include the following:

Optimize energy structure and improve transport equipment: Government and enterprise should achieve full combustion of energy, improve energy utilization rate, and encourage the development and utilization of new clean and renewable energy sources, such as solar energy. However, old and high-energy-consuming vehicles should be limited in entering into the transportation market. The transportation tools with old technology, high energy consumption, high discharge, and low inefficiency should be eliminated. Utilizing environmentally friendly and low-carbon logistic equipment should be encouraged. The overall carbon emissions in logistics industry should be reduced through the optimized adjustment of energy consumption structure and the improvement of transportation.

Develop multimodal transportation and optimize transportation structure: Multimodal transportation has evident environmental benefits. It can effectively save energy, and significantly reduce the discharge and the noise while greatly reducing the cost for long distance transportation, thereby shortening the delivery time to the largest extent and sharply reducing traffic congestion. The multimodal transport system dominated by the low-carbon transportation tools, such as rail and water transportation, should be immediately established. The transportation structure should be optimized, and a full play to technical and economic characteristics of different transportation tools should be provided.

Integrate logistics resources and improve logistics links: Government and enterprise should integrate existing resources, optimize the allocation of resources, conduct scientific and reasonable planning on logistics nodes, and avoid

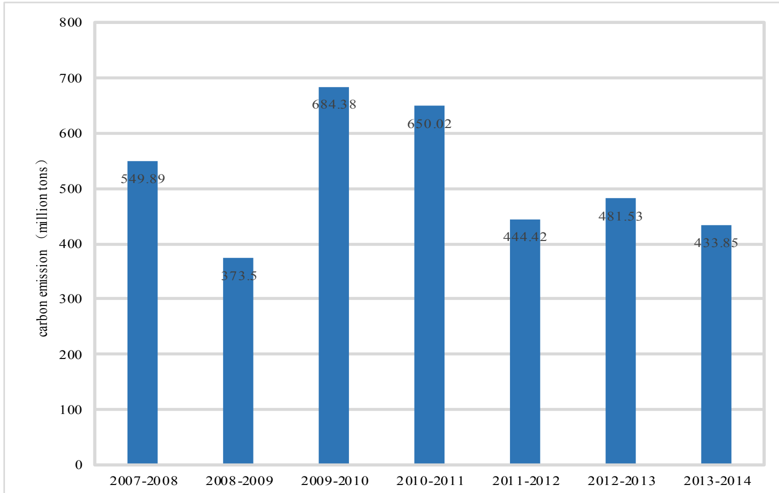

Fig. 3: Variation of carbon emissions of regional logistics ecosystems in Jiangsu due to economic scale.

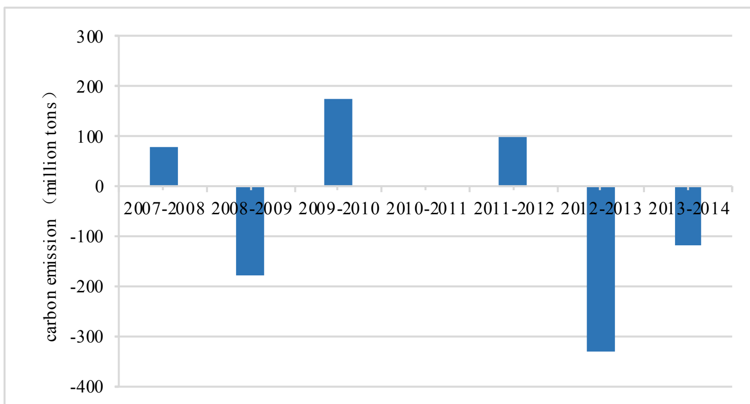

Fig. 4: Variation of carbon emissions of regional logistics ecosystems in Jiangsu due to industrial structure.

repeated construction of logistics facilities to reduce resource waste; improve high energy consumption, high discharge, and high cost situations in logistics industry; and maximize utilization efficiency of logistics resources.

Encourage technological innovation and promote energy conservation: Government and enterprise should encourage technology innovation and the application of energy conservation and discharge reduction devices in transportation domain to promote technical energy conservation and discharge reduction in transportation domain. We should emphasize and encourage the research, development, and application of new energy vehicles represented by hybrid fuel, fuel cells, and electric vehicles; actively adopt advanced information technology, such as global positioning system geographic information system, transportation management information system, and vehicle and cargo matching information platform; optimize transportation; avoid unreasonable transportation methods; reduce transportation capacity waste and oil consumption; and finally achieve energy conservation and discharge reduction.

Scientifically formulate carbon reduction policies of logistics: The regional inequalities in carbon emissions in logistics industry are evident. Further pertinence in the formulation of carbon emission reduction policies should be provided. For regions with small areal variations of carbon emission inequality, a uniformed carbon emission reduction policy should be considered. For regions with large areal variations of carbon emissions, the industry carbon reduction policy should be varied according to the actual situation in each location. Local governments can combine the actual situation of local logistics industry development level and carbon emissions with the formulation and gambling of principles on carbon emission reduction and trading to promote the low-carbon development of regional logistics.

CONCLUSIONS

To analyse accurately the areal variation characteristics and influencing factors of carbon emissions of regional logistics ecosystems, a Theil index model was established to measure these areal variations of carbon emissions between regions and within regions in this study; moreover, the main influencing factors of carbon emissions was identified by using the LMDI decomposition model, and the empirical analysis of Jiangsu Province in China was conducted. The following conclusions are drawn:

1. The established Theil index model is objectively and accurately to measure the areal variations in carbon emissions of regional logistics ecosystems and the overall variations in these carbon emissions should be divided into variations between regions and within regions.
2. The established LMDI decomposition model decomposes the influencing factors of carbon emissions of regional logistics ecosystems into energy structure, economic scale, and industrial structure factors and reveals the effect of all types of factors.
3. The empirical analysis of Jiangsu province of China shows that energy structure, economic scale, and industrial structure have a close inner link with logistics carbon emissions. Among them, economic scale and energy structure play positive roles in the carbon emissions of regional logistics ecosystems in Jiangsu province, and economic scale is the main reason for the increase in carbon emissions in the regional logistics ecosystem. However, industrial structure plays an adverse role in carbon emissions of regional logistics ecosystems.

The present study is based on the perspective of ecological civilization construction and green logistics development. It constructs the Theil index measurement model and the LMDI factor decomposition model of carbon emissions of regional logistics ecosystems. The method is easy to calculate and operate; thus, it is advantageous to the analysis of regional inequality level of carbon emissions and it can reveal the mechanism of the variation characteristics and the main influencing factors. Therefore, our study can provide basis for regional logistics ecosystem construction and process control, and reference and guidance for scientific formulation on differentiated discharge reduction policies.

The study provides new decision-making methods to analyse quantitatively the inequalities in carbon emissions of regional logistics ecosystems. It is of great significance to the dynamic management and evaluation of regional logistics ecosystems construction. However, this study did not conduct sufficient analysis, utilization, and excavation of relevant data. Moreover, only the influence of carbon emissions of regional logistics ecosystems from energy structure effect, economic scale effect, and industrial structure was analysed. Nevertheless, these limitations can be the direction for further research in the future to fit the theoretical and practical significance of the issue researched effectively.

ACKNOWLEDGEMENTS

This study was supported by the national natural science fund project (71403096) of China and the research project (2015-K1-033) of Ministry of Housing and Urban-Rural Development of China.

REFERENCES

Ageron, B., Gunasekaran, A. and Spalanzani, A. 2012. Sustainable supply management: an empirical study. International Journal of Production Economics, 140(1): 168-182.

Benjaafar, S., Li, Y. and Daskin, M. 2013. Carbon footprint and the management of supply chains: insights from simple models. IEEE Transactions on Automation Science and Engineering, 10(1): 99-116.

Chaabane, A., Ramudhin, A. and Paquet, M. 2012. Design of sustainable supply chains under the emission trading scheme. International Journal of Production Economics, 135(1): 37-49.

Harris, I., Naim, M. and Palmer, A. et al. 2011. Assessing the impact of cost optimization based on infrastructure modelling on CO_2 emissions. International Journal of Production Economics, 131(1): 313-321.

He, J., Yin, S.K. and Yao, H.Y. 2015. Analysis of multi-index measurement of regional difference in Zhe Jiang province based on Theil exponential. Modern Economy, (23): 120-122.

He, L.M. 2017. Retrospection in 2016 and prospection in 2017 of China's logistics industry. Logistics Technology and Implementation, 31(3): 48-52.

Jin, F.H., Fu, L.Y. and Ma, H.W. 2015. Measurement of carbon emission of regional logistics and research of gravity track. Development Research, 181(6): 14-17.

Kristina, L., Martin, C. and Dan, A. 2015. Using a transport portfolio framework to reduce carbon footprint. The International Journal of Logistics Management, 26(2): 296-312.

Liu F., Cai, Q. and Chen, S. et al. 2015. A comparison of the energy consumption and carbon emissions for different modes of transportation in open-cut coal mines. International Journal of Mining Science and Technology, 25(2): 261-266.

Liu, B.Q., Cheng, K. and Ma, Z.X. 2016. Research on influence of urbanization on carbon emission's change in logistics industry. Resource and Environment of Population in China, 26(3): 54-60.

Liu, J., Li, H.J. and Yu, Q.W. et al. 2015. Analysis of affecting factors of industrial waste gas in Xu Zhou based on the LDML decomposition model. Market of Economy of Science and Technology, (12): 116-117.

Luo, Z., Gunasekaran, A. and Dubey, R. et al. 2016. Antecedents of low carbon emissions supply chains. International Journal of Climate Change Strategies and Management, 9(5): 707-727.

Matthews, H.S., Hendrickson, C.T. and Weber, C.L. 2008. The importance of carbon footprint estimation boundaries. Environmental Science, Technology, 42(16): 5839-5842.

McKinnon, A.C. and Piecyk, M.I. 2009. Measurement of CO2 emissions from road freight transport: a review of UK experience. Energy Policy, 37(10): 3733-3742.

McKinnon, A.C. and Woodburn, A. 1996. Logistical restructuring and road freight traffic growth: an empirical assessment. Transportation, (23): 141-161.

Piecyk, M.I. and Mckinnon, A.C. 2010. Forecasting the carbon footprint of road freight transport in 2020. International Journal of Production Economics, 128(1): 31-42.

Sundarakani, B., Souza, R.D. and Goh, M. et al. 2010. Modeling carbon footprints across the supply chain. International Journal of Production Economics, 128(1): 43-50.

Tacken, J., Rodrigues, V.S. and Mason R. 2014. Examining CO2e reduction within the German logistics sector. International Journal of Logistics Management, 25(1): 54-84.

Zhang, J. and Cai, J.F. 2014. Measurement and decomposition of difference in carbon emission zone of logistics industry in China. Circulation Economy in China, (8): 25-30.

Zhou, L.Y., Gu, Z.H. and Zhao, G. et al. 2015. Calculation and evaluation of carbon dioxide emissions of regional logistics ecosystem: a study in China. Nature Environment & Pollution Technology, 88(8): 1227-1236.