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Container Ports Multimodal Transport in China from the View of Low Carbon

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Contents

Abstract

The study uses the carbon dioxide emission calculation model published by IPCC to measure carbon dioxide emissions and fuel inputs of the three types of multimodal transport (road-sea, railway-sea, and river-sea) in ports of China. Then, we make a case study on Shanghai port. Combined with carbon taxes launched around 2012 in China, this paper calculates the carbon taxes on the three types of multimodal transport and makes a pairwise comparison between roadway/railway, roadway/waterway and waterway/railway. The results show that increasing the proportion of railway-sea transportation and river-sea transportation to a reasonable level will achieve great energy saving, emission reduction, and economic benefits. According to different transportation network features, this paper applies Cluster analysis to raise separately suggestions for long-term development of coastal container ports in China based on low-carbon thinking.

Key words : Low carbon port, multimodal transport, Carbon dioxide emission, Cluster analysis

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I. Introduction

Global warming is getting more and more attention. The whole society focuses on the low carbon and many experts do low carbon studies on industries. However, there is little research on low-carbon ports. According to the data from United Nations, since 1990, the emission of greenhouse gas from global trading vessels has increased by 85% and the emission of greenhouse gas from the shipping activities each year accounts for more than 3% of the global gross emission, which exceeded that of all the economic departments of the United Kingdom putting together. Therefore the study that focuses on the necessary and feasibility of developing low-carbon ports is urgent.

Low carbon economy means an economy model based on the low power consumption, low pollution and few carbon emissions. Although port industry makes remarkable economic benefits, it causes serious damages to environment meanwhile. Shipping and hinterland transportation account for a large proportion of the world's energy consumption and carbon emission. If the transport modes can be adjusted, from the perspective of energy saving and the reduction of carbon emission, the low-carbon development in seaport will be realized feasibly.

This paper attempts to provide data support and practical guidance for building low-carbon ports. Shanghai port, the largest scale and highest reputation port in China, has been chosen as a case for empirical study. This paper is divided into six parts. The first part is introduction. It introduces the background, methodology and objective of the paper. The second part includes literature review and background of low carbon ports in China. The third part is CO_2 emission of multimodal transport. It introduces the method to calculate CO_2 emissions of transportation and estimates the CO_2 emissions of the three multimodal transport modes, road-sea, rail-sea and river-sea transport. Then, it compares the structure of multimodal transport system of seaports between China and Europe.

The fourth part is empirical study of low carbon port based on the case of Shanghai port. In this part, it compares the three types of multimodal transport of Shanghai port in CO_2 emissions and energy inputs. It also analyzes the carbon taxes on the three types of multimodal transport in Shanghai port. The fifth part is strategies to further develop multimodal transport of low-carbon ports in China. With the problems mentioned in part three and four, according to the differences of transportation networks in Chinese coastal provinces, it employs Cluster analysis and proposes different suggestions and polices for long-term development of low-carbon port container multimodal transport in southern and northern seaports. Finally, the sixth part is the conclusion.

II. Literature Review and Background of Low Carbon in China

1. Literature review

Although there is little research on the low-carbon ports container multimodal transport, there are considerable amount researches on green port and low-carbon economy. In the side of green port performance, the researches focus on the empirical analysis of green ports abroad and in China. The major achievement is the establishment of evaluation index system of green port by using DEA.1) About the low-carbon economy, the urgency, necessity and feasibility of developing low-carbon economy in China has been explained and analyzed completely.2)

With the development of low-carbon economy, the researches on low-carbon industry are also increasing. The need of developing low-carbon agriculture was put forward firstly.3) However, in the literature review, previous studies have rarely involved the theoretical support of low-carbon port development, more particularly the lack of quantitative research methods. For the few typical research achievements, the fifth generation port was considered to be low-carbon port, which marked the development of ports in the world has entered a new phase.4) There are also some researches pointed out that more attention to the economic development of low-carbon ports has to be given.5) And the professional research on the way of energy saving proposed that China required both sides of energy conservation and technological

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1) Fan (2009), pp.21-23; Guo (2007), pp.138-140; Jiang and Zhang (2008), pp.22-24.

2) Guo (2011), pp.108-111.

3) Zhang, Pan and Cui (2008); Zhang (2009), pp.5-13; Zhang (2010), pp.26-28; Sun (2009), pp.4-11.

4) Li and Wang (2010), pp.10-12.

5) Chen (2009).

innovation to develop low-carbon economy.[6)] The CNECCO model has been constructed based on energy, using the system mechanics to simulate energy metabolism in various economic sectors.[7)] Besides, the relationship between each region carbon emissions, economic development, industrial structure and energy efficiency has been analyzed in quantitative method, using the panel data of 30 Chinese provinces from 1995 to 2005. It showed that there was an inverted U-curve trend between carbon emissions and economic development but a U-curve relationship between carbon emissions and energy consumption intensity.[8)]

In the side of low-carbon development of multimodal transport, studies concentrate on the container rail-sea transport. The importance and necessity of rail-sea transportation to the development of low carbon ports has been explained through empirical analysis.[9)]

2. Backgrounds of Low carbon in China

In “UK Energy White Paper” (2003), the low-carbon is firstly defined as getting more economic output through, less natural resource consumption and less pollution. In August 2009, titled “Chinese Energy Technology Roadmap Until 2050”, the Chinese Academy of Sciences on the “low-carbon economy” is defined as: low-carbon economy is an economy model that is based on the low power consumption, low pollution, low emission. The substance of low-carbon economy is efficient use of energy, development of clean energy, the pursuit of green GDP. The core is the technology innovation of energy and emission reduction, industrial structure and institutional innovation and the fundamental change of the conception of human survival.[10)]

However, the economic development of China is still at the heavy-industry-led phase of high carbon intensity in the backdrop of urbanization and industrialization.[11)] The energy endowment in China is mainly coal of high carbon intensity which brings about serious waste of energy and environmental pollution, and, therefore, is under heavy stresses of reducing the emission of CO_2. According to the data of the World Bank, Energy

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6) Dong (2009), p.1.
7) Xu, Zhang and Zhang (2009), pp.31-32.
8) Wen (2008).
9) Zou (2009), pp.33-34.
10) Ou and Jiang (2010), pp.49-53; Huang and Lin (2011), pp.49-50.
11) Sun (2009), pp.4-11.

Consumption per unit of GDP in China is 4.52 toe/1,000 US$ which is 2.23 times more than the average level of the world(2.03toe/1,000US$), 2.94 times more than the level of United States(1.54toe/1,000US$) and 4.82 times more than the level of Japan(0.94toe/1,000US$). This clearly shows the poor efficiency of energy using in China. With the rising awareness of green economic development around the world, it is no doubt that China should make more efforts on the low-carbon development in both economy and the whole society.

Port industry, taking off rapidly since the reform and opening up, has made remarkable economic benefits. With the rapid development of ports, the total containers throughput of China is increased by 56.1% (from 93.61 million TEU in 2006 to 146.13 million TEU in 2010) during the Eleventh Five-Year. This swift growth brings great pressure on the ports' container inland transport system. Especially for road transport, because the container inland transport mainly relies on road transport and the percentage of containers dispatched by road transport is more than 80%, the road transport congestion is getting seriously. Taking Donghai Bridge which connects Shanghai and Zhejiang as an example, the design capacity is 7.04 million TEU in a year but actual volume of containers passed through the bridge is 13.64 million TEU in a year. Besides, according to the China Yearbook 2010, transportation industry including port industry is the third most energy consumptions sector of all the sectors in China. Due to its industrial features of high-energy consumptions and high pollution, the transport and port industry bear the inescapable responsibility for the task of energy saving of the society. With the coming of low-carbon era and the acceleration of global economic integration, the index system of "green trade barriers" begins to emerge more and more frequently in international trade. The reasonable structure of hinterland transport modes' of seaports could not only benefit the environment protection, but also improve the international competitiveness of Chinese seaports.

III. CO_2 Emission of Multimodal Transport

It is urgent for Chinese seaports to create an economy model based on low energy consumption, low pollution and low carbon emission, and make a fundamental change on the industrial structure as well as hinterland transport mode. Therefore, in the research of developing low-carbon ports in China, this paper will take the perspective from hinterland multimodal transport of Chinese seaports, which includes road-sea, rail-sea and river-sea combined transportation.

1. Model of Calculating carbon dioxide emission

This paper chooses the carbon dioxide emission calculation model published by 2006 IPCC12) Guidelines for National Greenhouse Gas Inventories to measure carbon dioxide emissions. The measurement methods employed by 2006 IPCC Guidelines has gained general acceptance amongst countries as the basis for inventory development. By adopting these methods, any country, regardless of experience or resources, should be able to produce reliable estimates of their emissions of these gases. In particular, default values of the various parameters and emission factors required are supplied by IPCC for all sectors, so that, at its simplest, a country needs only supply national activity data. And in IPCC 2006 Guidance, these methods are also improved so that the final estimates are neither over- nor under-estimates as far as can be judged nor uncertainties are reduced as far as possible. This makes it possible to measure CO_2 emissions when some particular statistics data is difficult to obtain.13)

In addition, the National Greenhouse Gas Inventories (NGGI) is provided by China's government every two years. The researches in the inventory are based on the methods employed by 2006 IPCC Guidelines. As a result, adopting the methods provided by IPCC to measure CO_2 emissions makes sure the results of this paper retaining comparability and consistency with the country's researches.

According to 2006 IPCC Guidelines for National Greenhouse Gas Inventories, transportation vehicles are the sources of mobile combustion, and their emissions can be estimated from either the fuel consumed (represented by fuel sold) or the distance travelled by the vehicles. In general, the first approach (fuel sold) is appropriate for CO_2 and the second one (distance

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12) IPCC: Intergovernmental Panel on Climate Change.

13) Zhang (2010), pp.21-28.

travelled by vehicle type and road type) is appropriate for CH_4 and N_2O. Emissions of CO_2 are best calculated on the basis of the amount and type of fuel combusted and its carbon content. Therefore, the CO_2 emissions of one transport mode can be gained from the product of its fuel consumption and the CO_2 emissions of unit fuel consumption.

The CO_2 emissions of transport mode a can be estimated by the formula (3.1)

$$W_a = \sum G_{ai} \times F_i \tag{3.1}$$

W_a: The CO_2 emissions of transport mode a. (Kg-CO_2)
G_{ai}: The consumptions of fuel i of transport mode a. (Kg)
F_i: The CO_2 emissions coefficient of fuel i, the CO_2 emissions of unit fuel consumption. (Kg-CO_2/Kg)

While F_i, the CO_2 emissions coefficient of fuel i, can be calculated by the formula (3.2)

$$F_i = M_i \times EF_i \tag{3.2}$$

M_i: The net calorific value of fuel i (TJ/Gg)
EF_i: The CO_2 emission factor of fuel i (Kg-CO_2/TJ)

The net calorific value is the release of caloric from the combustion of unit fuel and the CO_2 emission factor is the CO_2 emissions of unit caloric from the combustion of fuel. The CO_2 emissions coefficient can be calculated by the product of the net calorific value of fuel and the CO_2 emission factor of the same fuel.

2. Data source and result analysis

In this paper, the data of the CO_2 emission factor and the net calorific value of fuel are supplied by 2006 IPCC Guidelines. The data of the energy consumptions of road, rail and inland shipping transport' are supplied by China Communication Yearbook 2011 and the Key Data on the National Highway and Waterway Traffic Special Survey Bulletin published by the Ministry of Communication in 2010. To facilitate the estimation and comparison, the energy consumptions of the three transport modes has been converted into the unified measurement unit and the unit is kg/tkm which means the energy consumption for carriage per ton goods to per kilometer.

The main vehicles of container road transportation are diesel trucks and per vehicle average carrying 25 tons goods or 2 TEU. For this reason, this paper chooses the energy consumptions of diesel trucks which carry more than 20 tons goods as the energy consumptions of container road transportation. There are two types of locomotives, diesel locomotive and electric locomotive. Diesel locomotive is often used for freight transport and electric locomotive is often used for passengers transport in China. For this reason, this paper selects the energy consumptions of diesel locomotive as the energy consumptions of railway transportation. The data about the length of transportation routes of provinces in China are supplied by China Communication Yearbook 2011.

According to the formula 3.1 and 3.2, CO_2 emissions of the three transport modes are displayed in the Table 2.

<Table1> CO_2 emissions from different transport modes in China

	Unit	Roadway	Railway	Waterway
Energy consumptions	Kg/tkm	0.01505	0.00264	0.00544
CO_2 emissions	Kg-CO_2/tkm	0.04795	0.00841	0.01733

Based on the table 1, road transport has the most energy consumptions and CO_2 emissions. CO_2 emissions of trucks carrying one ton goods for one kilometer are 47.95g, which is 5.7 times more than rail transport and 2.8 times more than waterway transport. As a result, higher the proportion of road transport mode, the CO_2 emissions of container transport system is more. Increasing the proportion of rail-sea transport by 1%, the ratio of energy saving and emissions reduction is up to 82.5% and improving waterway transport's percentage by 1%, the ratio is up to 64.3%.

3. Comparison of main ports between Shanghai and Rotterdam

Each advanced international shipping centers around the world has their own characteristics in container transport systems. But the common feature is that they develop their container transport system according to their geographical locations, economy strength and the economic environment. Taking Rotterdam port which is located in the Rhine and the Maas River estuary and west of the North Sea as an example, the ratio of railway, road and waterway transport mode in its container transport system is 1:6:3 (see Table 2). However, in China most of seaports share the similar mode that is depending on road-sea transport to dispatch containers. Railway and waterway transport mode occupy a very small proportion. Taking Shanghai port located in the Yangtze River Delta area for illustration, the ratio of the three transport modes in its container transport system is demonstrated in Table 2.

<Table 2> The ratio of different transport modes
for Shanghai port and main European ports

	Railway (%)	Roadway (%)	Waterway (%)
Shanghai	3.0	87.0	10.0
Rotterdam	10.9	58.6	30.5
Antwerp	7.0	50.0	43.0
Le Havre	5.1	86.8	8.1
Hamburg	28.7	69.0	2.3

Source: China Ports Year Book 2010

Shanghai and Rotterdam share the similar geographical locations which are located in the estuary of major rivers and own rich inland waterway resources and developed highway network. Both of them are the most important port in their countries even in the world and they have vast and economically advanced hinterland. From table 2, it clearly shows that the structure of container transport system in Rotterdam can make full use of the three transport modes, which is more reasonable. While Shanghai port overly depend on its roadway transportation, which causes more and more serious traffic congestion in highway network connecting Shanghai port and the city. From the view of energy saving and emission reduction, what benefits can Shanghai port obtain if it can take full advantage of the transport modes as Rotterdam?

Then, as an example, we calculate CO_2 emissions of three transport modes of Shanghai port with the throughputs amount in 2010, and compare the three transport modes which are adjusted on the ratio of Rotterdam in CO_2 emissions. In 2010, container throughput in Shanghai port is 29.07 million TEU (weighted 348.84 million tons) and the average goods transported distance is 248.7 kilometer. According to these statistics and the emissions formula, we can get the results as follows.

<Table 3> CO_2 emissions comparison of Shanghai port before and after adjustment

Unit: million tons

	Before Adjustment		After Adjustment	
	Dispatched Volume	CO_2 emissions	Dispatched volume	CO_2 emissions
Roadway	303.49	3.62	174.42	2.08
Railway	10.47	0.02	34.88	0.07
Waterway	34.88	0.15	139.54	0.60
Total	348.84	**3.79**	348.84	**2.75**

As illustrated in Table 3, there are 1.04 million tons CO_2 emissions reduced after adjusting the multimode transportation structure. And the percentage of the reduction of CO_2 emission is 27.47%. It is obviously that the current multimodal transport system of Chinese seaports is unreasonable and seaports should regulate the proportion of the three transport modes.

IV. Empirical study of Low Carbon Port : the case of Shanghai port

Shanghai port is the largest foreign trade and container port in China. Shanghai port is located in the south coast of China and is the main port of the Yangtze River system. It completed 6.54 billion tons of cargo throughputs and 29.069 million TEU of container throughputs in 2010, which ranked the first place in the world. Shanghai port owns vast economic hinterland and there are cargos from thirty-one provinces loaded and unloaded or transshipped by Shanghai port.

1. The analysis on the energy inputs and carbon dioxide emissions of multimodal transport

According to the formula 3.1, 3.2 and the relevant data, the results are showed in the following table.

<Table 4> The energy inputs and CO_2 emissions of road-sea and rail-sea transport mode

% of multimodal transport[14)]		unit	10	20	30	40	50	60	70	80	90
Volume of container multimodal transport		10,000 TEU	290.7	581.4	872.1	1,162.8	1,453.5	1,744.1	2,034.8	2,325.5	2,616.2
Equivalent weight of container multimodal transport		million tons	34.8	69.8	104.6	139.5	174.4	209.3	244.2	279.1	313.9
Energy input	Roadway	10,000 tons	15.7	31.5	47.2	63.0	78.7	94.5	110.2	126.0	141.7
	Railway	10,000 tons	2.8	5.5	8.3	11.1	13.8	16.6	19.3	22.1	24.9
Energy saving		10,000 tons	12.9	26.0	38.9	51.9	64.9	77.9	90.9	103.9	116.8
CO_2 emission	Roadway	10,000 tons	50.2	100.4	150.5	200.7	250.9	301.1	351.3	401.5	451.6
	Railway	10,000 tons	8.8	17.6	26.4	35.2	44.0	52.8	61.6	70.4	79.2
Reductions of CO_2 emission		10,000 tons	41.4	82.8	124.1	165.5	206.9	248.3	289.7	331.1	372.4

According to table 4, we compare the road-sea transportation with the rail-sea transportation in both energy input and CO_2 emissions. The number of containers dispatched by the road-sea transportation accounts for 10%, the energy input and CO_2 emissions are 157 and 502 thousand tons separately. And the number of containers dispatched by the rail-sea transportation accounts for 10%, the energy input and CO_2 emissions are 28 and 88 thousand tons separately. With the percentage increased to 90%, the energy input and CO_2 emissions of road-sea transportation are 1.417 and 4.516 million tons separately. And in terms of rail-sea transportation, the energy input and CO_2 emissions of rail-sea transportation are 0.249 and 0.792 million tons separately in the same percentage. As a result, increasing the proportion of rail-sea transportation by 1%, there are 41.4 thousand tons and 12.9 thousand tons of CO_2 emissions and fuel inputs reduced separately. In the other side, adopting the rail-sea transport mode, the energy saving and CO_2 emissions reduction are separately 0.044 and 0.14 tons per TEU.

The table 5 contrasts the road-sea transportation to the river-sea transportation

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14) % of multimodal transport: the percentage of containers dispatched by road-sea or rail-sea transport mode in Shanghai port.

in respect of energy input and CO_2 emissions.

<Table 5> The energy inputs and CO_2 emissions of road-sea transport and river-sea transport

% of multimodal transport*		unit	10	20	30	40	50	60	70	80	90
Volume of container multimodal transport		10000 TEU	290.7	581.4	872.1	1162.8	1453.5	1744.1	2034.8	2325.5	2616.2
Equivalent weight of container multimodal transport		million tons	34.8	69.8	104.6	139.5	174.4	209.3	244.2	279.1	313.9
Energy input	Roadway	10000 tons	15.7	31.5	47.2	63	78.7	94.5	110.2	126	141.7
	Waterway	10000 tons	5.7	11.4	17.1	22.8	28.5	34.2	39.9	45.5	51.2
Energy saving		10000 tons	10.0	20.1	30.1	40.2	50.2	60.3	70.3	80.5	90.5
CO_2 emission	Roadway	10000 tons	50.2	100.4	150.5	200.7	250.9	301.1	351.3	401.5	451.6
	Waterway	10000 tons	18.1	36.3	54.4	72.6	90.7	108.8	127	145.1	163.3
Reductions of CO_2 emission		10000 tons	32.1	64.1	96.1	128.1	160.2	192.3	224.3	256.4	288.3

* % of multimodal transport: the percentage of containers dispatched by road-sea or river-sea transport mode in Shanghai port.

The table 5 shows that with the proportion of river-sea transportation improved by 1% in Shanghai port, there are 32.1 thousand tons and 10 thousand tons of CO_2 emissions and fuel inputs reduced separately. In the other side, adopting the river-sea transport mode, the energy saving and CO_2 emissions reduction are separately 0.034 and 0.11 tons per TEU. With increasing the river-sea transportation's percentage in Shanghai port, the energy saving and the reduction of CO_2 emissions also show a linear growth trend, which is similar to the rail-sea transport mode. Contrasting to the railway-sea transportation, energy inputs and CO_2 emissions of river-sea transportation are about 2 times more than railway-sea transportation per TEU.

2. The analysis on the carbon taxes on multimodal transport

If carbon tax is collected, the modes of railway-sea transportation and river-sea transportation would bring huge economic benefits contrast to the present container transport mode. According to the suggestions of the Ministry of Finance and the Research Group of the Ministry of Environmental Protection and Planning Institute, it is appropriate for China to collect carbon tax with 10~20 Yuan per ton of carbon dioxide emission around 2012 and this may be raised to 40~50 Yuan per ton of carbon dioxide emission in 2020. This paper estimates carbon taxes based on the assumption that the average weight of per TEU is 12kg, the average transport distances is 300km and the carbon tax is 20 Yuan per ton of CO_2 emission.

The table 6 contrasts the road-sea transportation to the rail-sea transportation in terms of carbon taxes.

<Table 6> Carbon taxes on road-sea transportation and railway-sea transportation

% of multimodal transport		unit	10	20	30	40	50	60	70	80	90
Volume of container multimodal transport		10,000 TEU	290.7	581.4	872.1	1,162.8	1,453.5	1,744.1	2,034.8	2,325.5	2,616.2
Equivalent weight of container multimodal transport		million tons	34.8	69.8	104.6	139.5	174.4	209.3	244.2	279.1	313.9
Carbon taxes	Roadway	10,000 Yuan	1,003.7	2,007.3	3,011.0	4,014.6	5,018.3	6,021.9	7,025.6	8,029.3	9,032.9
	Railway	10,000 Yuan	176.1	352.1	528.2	704.2	880.3	1,056.3	1,232.4	1,408.5	1,584.5
Savings on transportation cost		10,000 Yuan	827.6	1,655.2	2,482.8	3,310.4	4,138.0	4,965.6	5,793.2	6,620.8	7,448.4

According to the table 6, the carbon taxes are 10.037 million Yuan with 10 percent of containers dispatched by road-sea transport mode and 1.761 million Yuan with 10 percent of containers dispatched by rail-sea transport mode. As a result, with the proportion of railway-sea transportation improved by 1%, the savings are 827.6 thousand Yuan. In the other side, the tax reduction is 2.85 Yuan per TEU by employing the rail-sea transportation.

The table 7 contrasts the road-sea transportation to the river-sea transportation in terms of carbon taxes.

<Table 7> Carbon taxes on road-sea transportation and river-sea transportation

% of multimodal transport		unit	10	20	30	40	50	60	70	80	90
Volume of container multimodal transport		10,000 TEU	290.7	581.4	872.1	1,162.8	1,453.5	1,744.1	2,034.8	2,325.5	2,616.2
Equivalent weight of container multimodal transport		million tons	34.8	69.8	104.6	139.5	174.4	209.3	244.2	279.1	313.9
Carbon taxes	Roadway	10,000 Yuan	1,003.7	2,007.3	3,011.0	4,014.6	5,018.3	6,021.9	7,025.6	8,029.3	9,032.9
	Waterway	10,000 Yuan	362.8	725.6	1,088.4	1,451.1	1,813.9	2,176.7	2,539.5	2,902.3	3,265.1
Savings on transportation cost		10,000 Yuan	640.9	1,281.7	1,922.6	2,563.5	3,204.4	3,845.2	4,486.1	5127	5,767.9

According to table 7, the carbon taxes are 10.037 million Yuan with 10 percent of containers dispatched by road-sea transport mode and 3.628 million Yuan with 10 percent of containers dispatched by river-sea transport mode. Therefore, with the percentage of river-sea transportation improved by 1%, the savings are 640.9 thousand Yuan. In the other side, the tax reduction is 2.2 Yuan per TEU by adopting the river-sea transportation. Contrasting to the railway-sea transportation, the carbon taxes of river-sea transportation are 2.06 times more than railway-sea transportation per TEU. The larger container throughput in seaport, the larger enormous economic benefits will be enjoyed by employing the railway-sea transportation or river-sea transportation.

V. Suggestions to the development of low-carbon ports in China

The results from the case study on Shanghai port shows that improving the ratio of rail-sea transportation or river-sea transportation could produce huge economic benefits from energy saving, CO_2 emissions reduction and carbon taxes reduction. Therefore, the reasonable structure of container transport system could play a positive role in the achievement of low-carbon development in China. From the *Twelfth Five-Years Transportation Planning of the Ministry of Communication,* China will actively promote the development of multimodal transport and focus on the construction of rail-sea transport mode and river-sea transport mode. However, because of nature factors, there is a great difference in the side of railway network and waterway network among each coastal province in China. Table 8 shows the difference.

<Table 8> The Length of highway, railway lines and inland waterway of Chinese coastal province

Unit: kilometer

Province	LH[15]	Ratio	LR	Ratio	LW				
					Grade1	Grade2	Grade3[16]	Total	Ratio
Tianjin	982	3.14%	781.5	3.09%	0	0	0	0	0.00%
Hebei	4,307	13.77%	4,880.3	19.27%	0	0	0	0	0.00%
Liaoning	3,056	9.77%	4,229.3	16.70%	0	0	56	56	1.63%
Shandong	4,285	13.70%	3,685.7	14.55%	0	0	253	253	7.35%
Shanghai	775	2.48%	317.7	1.25%	117	59	43	219	6.36%
Jiangsu	4,059	12.98%	1,655.6	6.54%	370	429	386	1,185	34.44%
Zhejiang	3,383	10.82%	1,678.2	6.63%	14	12	147	173	5.03%
Fujian	2,351	7.52%	2,109.7	8.33%	108	20	52	180	5.23%
Guangdong	4,839	15.47%	2,478.6	9.79%	57	0	737	794	23.07%
Guangxi	2,574	8.23%	3126	12.34%	0	0	572	572	16.62%
Hainan	660	2.11%	387.3	1.53%	9	0	0	9	0.26%
Total	**31,271**	**100.00%**	**25,329.9**	**100.00%**				**3,441**	**100.00%**

Sources: China Communication Yearbook 2010

According to table 8, the high-grade channels of inland shipping are mainly in the south of China. The mileages of inland waterways in southern regions occupy 88.1% all over the country and the rivers with navigable capability of more than kilotons occupy 91.2% of all the high-grade lines. After years of construction and development, the Yangtze River has become one of the world’s busiest rivers. Xijiang River has become the important link to connect Southwest China to Hong Kong, Macao and Guangdong. And Yangtze River Delta as well as Pearl River Delta has become the important part of regional comprehensive transport system. The statistics of the provinces in south of China indicates that the inland waterway network is more developed than its railway network.

In the north of China, the railway network is more developed than its inland

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15) LH-Length of Highway; LR-Length of Railway lines; LW-Length of inland waterway.

16) Inland waterway grade is classified by the navigation capability of the river traffic channel. Grade1: 3000 tons; Grade2: 2000 tons; Grade3: 1000 tons.

waterway network. The length of railway lines in the 4 north coastal provinces accounts for 53.6% of all the railway lines in the 11 coastal provinces. While the length of inland waterways with navigable capability of more than kilotons in the 4 north coastal provinces only accounts for 8.98% of all the high-grade lines in the 11 coastal provinces.

Therefore, in order to propose a more practical guidance to the adjustment of seaport transport mode of Chinese coastal provinces, the method of Cluster Analysis has been brought in this research. Cluster analysis is a class of statistical techniques that can be applied to data that exhibit "natural" groupings. A cluster is a group of relatively homogeneous cases or observations. Objects in a cluster are similar to each other, while are dissimilar to the objects outside the cluster, particularly to the objects in other clusters.

In the case of constructing the multimodal transport systems of Chinese coastal provinces, it should decide which provinces should support the development of rail-sea transport mode, which provinces support river-sea mode, and which provinces support both of these two modes. Therefore, Squared Euclidean Distance is chosen to solve these issues. Squared Euclidean Distance is frequently used in optimization problems in which distances only have to be compared. It helps decide which clusters (provinces) should be combined (for agglomerative), or where a cluster (province) should be split (for divisive).

<Table 9> The percentage of railway and inland waterway in the length of transportation network

No.	Province	Percentage of railway	Percentage of inland waterway	Percentage of inland waterways with navigation capability more than 1,000 tons
1	Tianjin	0.0515	0.0058	0.0000
2	Hebei	0.0311	0.0000	0.0000
3	Liaoning	0.0400	0.0039	0.0005
4	Shandong	0.0160	0.0044	0.0011
5	Shanghai	0.0224	0.1566	0.0154
6	Jiangsu	0.0098	0.1428	0.0070
7	Zhejiang	0.0142	0.0820	0.0015
8	Fujian	0.0222	0.0342	0.0019
9	Guangdong	0.0124	0.0594	0.0040
10	Guangxi	0.0287	0.0498	0.0052

The data for Cluster Analysis is not chosen the length of the railway or inland waterway, but the percentage of them. The percentage is calculated by the length of railway or inland waterway in a province divided by the total length of the three modes in the province, which shows the ratio of railway or inland waterway in the structure of the area's entire transport network. And the data are shown in Table 9.

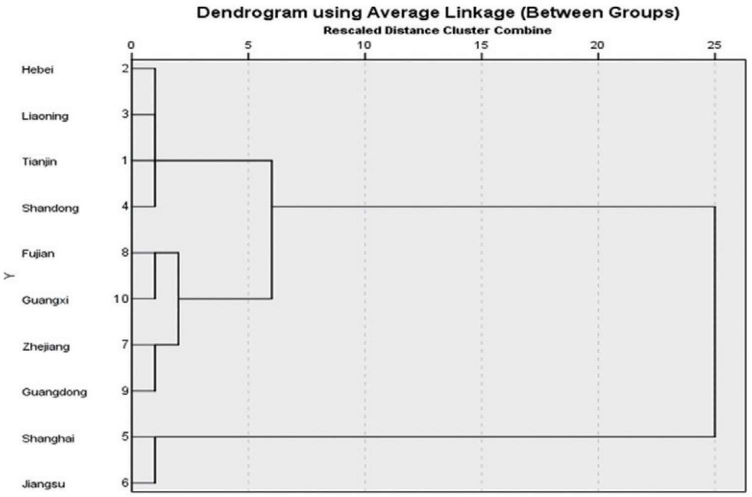
According to the data in table 9, SPSS is applied for cluster analysis and the results are demonstrated as follows.

Table 10 shows the clustering process of the 10 coastal provinces.

<Table 10> Agglomeration Schedule

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	2	3	.000	0	0	2
2	1	2	.000	0	1	6
3	8	10	.000	0	0	7
4	5	6	.000	0	0	9
5	7	9	.001	0	0	7
6	1	4	.001	2	0	8
7	7	8	.001	5	3	8
8	1	7	.004	6	7	9
9	1	5	.016	8	4	0

<Figure 1> Cluster analysis tree diagram



In table 10, “Cluster Combined” shows which clusters (provinces) should be combined and the “Coefficients” is the Squared Euclidean Distance which usually measures the degree of difference between the clusters (provinces) in terms of the structure of transportation network. Typically, the closer between clusters (provinces), the more "intimate" they are and the more likely they are clustered into one cluster; the farther between clusters (provinces), the more “alienated” they are and the more likely they belong to a different cluster. As shown in table 10, in the first stage, cluster No.2 (Hebei Province) and cluster No.3 (Liaoning Province) are gathered to a new cluster (No.2) which is expressed by the smaller number between the two clusters. Then in the second stage, cluster No.1 (Tianjin Province) and cluster No.2 (Hebei and Liaoning) are gathered to a new cluster No.1 which includes Tianjin, Hebei and Liaoning Provinces. And this process is demonstrated by Figure 1.

According to the cluster table and cluster tree diagram, coastal provinces in China can be divided into three groups.

The first group includes Hebei, Liaoning, Tianjin and Shandong. In this group, the proportion of railway network is about 8 times more than the inland waterway. Inland waterways of the 4 northern provinces are few, and most of them are l low-grade channels. As a result, seaports in these provinces should give priority to the development of railway-sea combined transport mode.

In these provinces, most port areas are not connected with freight rail lines. This adds the loading and unloading activities of vehicles, extends operation times and increases transportation costs in the process of container transit. Therefore, the 4 provinces should improve the railway connectivity between the ports and the hinterland. Moreover, the freight capacity of railway linking the port areas and the main hinterland should be increased to form a fast and reliable rail-sea transportation channel. Lastly, build a regional container multimodal center relying on the major railway container yard in the hinterland in order to attract shipping companies, freight forwarding and freight owners to enter and form a seamless rail-sea transportation service chain.

The second group includes Fujian, Guangxi, Zhejiang and Guangdong. In this group, the proportion of inland waterway network is 1.5 to 5 times more than the railway’s. Although the inland waterways are more than railways, the rivers with navigation capacity of more than ten-thousand-ton are few. As a result, seaports in these provinces should develop river-sea combined transport mode and strengthen the development of high-grade inland waterways to improve the navigation capability. Besides, they can also make full use of their railway network to develop railway-sea combined transport mode.

The third group includes Shanghai and Jiangsu. In this group, tthe proportion of inland waterway network is much higher than that of the railway. And the rivers with navigation capability of more than ten-thousand-ton occupy a certain proportion. For this group, seaports in the two provinces should concentrate on the development of river-sea combined transport mode. Firstly, upgrade the handling ability of river ports between seaports and the hinterland to meet the river-sea transportation requirements. Secondly, improve the freight capacity for river vessels. Thirdly, employ modern information technology to enhance the efficiency of river port services, and focus on the establishment of container multimodal transport information service system which can provide services including information sharing and integration for customs clearance between the seaports and river ports.

Besides, it is important to increase the government policy and financial support for low-carbon port development. Port is a hub connecting shipping and inland transportation. The transformation of the port relates to various interests. So it needs the government to set a series of strong and effective policies and regulations to promote the smooth development of low carbon economy. The transformation and development of container multimodal transport for low-carbon port not only rely on the efforts of the Port Authority and Transport Ministry, but also need the support from provincial and local government. Besides, China can learn the European and American experience in the development of port transportation networks. Meanwhile, handling equipment updates, new energy development and low-carbon technologies introduction require significant financial support. Therefore, provincial and local government should encourage foreign investors to participate in building low-carbon port.

VI. Conclusion

Lower CO_2 emissions of the multimodal transport in Chinese ports definitely contributes to the achievement of low-carbon economy development in China as a whole. Recent years, considerable amount researches focus on how to achieve low-carbon development in port and transportation industry. However, most of them are theoretical supports, there is very little quantitative study concentrating on the CO_2 emissions and energy consumptions of multimodal transport in port industry. Besides, only a few researches compare the three types of multimodal transport in CO_2 emissions and energy consumptions. There is hardly any research quantifies the relationship between CO_2 emission reduction and the ratio of multimodal transport.

This paper attempts to provide data support and practical guidance for the low-carbon development of multimodal transport in building low-carbon ports and contribute any value for other experts to make further research on low-carbon port multimodal transport in China. Firstly, the present study quantifies CO_2 emissions and energy consumptions of different transport mode. This paper also calculates the carbon taxes on different transport mode. Moreover, this paper makes a pairwise comparison between roadway/railway, roadway/waterway and railway/waterway in terms of CO_2 emissions, energy consumptions and carbon taxes. Secondly, the current study quantifies the relationship between CO_2 emission reduction and the ratio of multimodal transport. Thirdly, considering the differences which are caused by natural factors in the transportation networks structure between northern and southern China, this paper employs Cluster Analysis to propose suggestions for the development of multimodal transport in northern and southern China. This is vital for Chinese ports to choose appropriate multimodal transport mode to reduce CO_2 emissions and energy consumption, which may also affect the profits and the benefits through carbon taxes collection. However, the existing researches do not take into account the differences in the structure of North-South traffic networks.

Through estimation on energy consumptions, CO_2 emissions and carbon taxes of different mode of transportation, the results show that railway-sea transportation mostly contributes to the low-carbon ports development;

while road-sea transportation has the largest energy consumptions and CO_2 emissions.Based on the findings and the Cluster Analysis results, we propose suggestions for the selection of container multimodal transport modes of Chinese seaports.

Certainly our research still has many limitations. Firstly, the certain ratio of each transport mode of Chinese coastal provinces is not put forward. Secondly, the data used in this study did not include the analysis of origin/destination of cargo and freight routes according to final destination. The main reason for these limitations is the lack of the relevant statistics data. For example, there is lack of container transportation statistics data classified by final destinations, which makes it is difficult to do any analysis in this aspect. But, we will keep on focusing on these area, and attempt to solve these issues in the future research.*

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