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WORLD MARITIME UNIVERSITY

Shanghai, China

MODELS AND POLICIES OF PORT CARBON EMISSION REDUCTION: A CASE STUDY OF THE PORT OF DALIAN

By

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China

A research paper submitted to the World Maritime University in partial fulfillments
of the requirements for the award the degree of

MASTER OF SCIENCE

ITL

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Declaration

I certify that all the material in this research paper that is not my own work has been identified, and that no materials are included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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Abstracts

Title of Research paper: **Models and Policies of Port Carbon Emission Reduction: A Case Study of the Port of Dalian**

Degree: **M.Sc.**

The construction of reducing carbon emission is the inevitable choice for realizing sustainable development of harbor; meanwhile, it is the objective demand for port proposed by social progress, which represents the general trend that admits of no delay. Based on analyzing domestic and overseas carbon emission status as well as management, this paper summarizes that, the rubber-tyred gantry crane, as one of the major operating equipments in harbor, carries high oil consumption and carbon emission; so it is the major object of current port green reformation. From the full life circle prospective, this paper researches the change of carbon emission in gantry crane “fuel to electricity”. Taking Dalian Port as example, it implements empirical analysis to verify that gantry crane “fuel to electricity” plays significant role in reducing port carbon emission, which is beneficial to further motivate government to promote the course of gantry crane “fuel to electricity”, facilitate improvement of port environment, and realize sustainable development of port economy. In addition, the empirical analysis of benefit optimization model established in this paper proofs that, it is conducive to further mobilizing enterprises’ initiatives of gantry crane “fuel to electricity”, driving government to provide subsidy properly according to practical situation, and realizing maximization of social benefit.

KEYWORDS: Port, Carbon Emission Reduction, Fuel to Electricity, Full Life Cycle calculation method, Economic Optimization Model

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List of Abbreviations

RTG	Rubber-Tyred Gantry crane

Chapter 1 Introduction

1.1 Background

80% of the pollution in global climate change since the last century is caused by industrialized countries' hundreds of years' excessive emission; however, they have stepped into post-industrialized society crossing the stage with high resource consumption and pollution emission. Clean Energy and Safety Act passed by United States House of Representatives recently stipulated to implement trade sanction on the countries rejecting pollutant emission reduction standard since 2020. At present, many developing countries including China is in the mid-term state of industrialization and urbanization with relatively higher energy consumption and carbon emission, so they are facing challenges in energy saving and emission reduction. With the intensified strength of developing low carbon economy, China proposed to greatly develop green economy, combine closely to expand domestic demand and promote economic growth, cultivate the new economic growth point featuring low carbon, and accelerating the construction of economic system characterizing low carbon emission.

With world economic development, energy consumption is in tension; along with global warming, energy saving and emission reduction is the future trend of all industrial development. As the mainstay industry in national economic development, transportation consumes large energy. According to the statistical data of International Energy Agency, during recent years, the energy consumption of transportation occupies over 20% and it also is the important source of greenhouse gas emission; in the last decade, the total discharge volume of CO_2 around the world increased by 13% while the carbon emission growth rate from transportation was about 25%. That is to say, developing low carbon economy has reached consensus around the world, and developed countries in Europe as well as America have taken the development of low carbon economy as the major content. Meanwhile, China started to put emphasis on the development of low carbon economy with clearly pointing out in The 12th Five-year Plan of Transportation to promote economic development mode to transform into high efficiency, low energy consumption and emission, set up the idea of low carbon development, and facilitate the development of low carbon economy. As the important link of transportation, port industry has turned into urban major energy consumption and greenhouse gas emission. Therefore, in the development of low carbon economy, port shall comply with market development, innovate development mode, change development concept, and walk for the path of green and low carbon development.

Internationally, in June 2013, EU formulated shipping industry emission policy and announced to adopt 3 steps in policy of shipping industry emission reduction: firstly is that, since the year 2018, all major ships (more than 5000 tons regardless of the registration place) using EU ports shall monitor, report and check CO_2 emission with submitting annual emission report; secondly is setting target of green gas reduction target in shipping industry; thirdly is implementing economic emission reduction measures based on market. EU stipulated that, water transportation enterprises must fulfill the responsibility of monitoring and reporting ship carbon emission; the specific information includes ship energy efficiency data, annual carbon dioxide emission, annual total consumption, annual total time for sailing and the monitoring method applied, etc.

Thus, it is particularly important and urgent for China to research the theory as well as practice of port carbon emission management.

1.2 Purpose of research

Based on analyzing domestic and overseas port carbon emission status, and combining with national policy as well as strategic deployment of port carbon emission, this paper summarized the mainstream measured for reducing carbon emission both in China and other countries—gantry crane “fuel to electricity”.

However, whether gantry crane“fuel to electricity” can authentically reduce port CO_2 emission, only a few domestic and overseas researches carried out quantization on its emission reduction. In order to better mobilize ports’ initiative of implementing gantry crane “fuel to electricity”, from the perspective of full life cycle, this paper calculated traditional rubber-tyred gantry crane and the CO_2 emission of rubber-tyred gantry crane taking electric power as power. Meanwhile, it analyzed and compared the results so as to intuitively show the emission reduction effect of gantry crane “fuel to electricity”, which is beneficial to further promoting government to encourage enterprise to carry out transformation of gantry crane and realize sustainable development of port.

In addition, this paper researched on the dynamic planning of gantry crane “fuel to electricity” so that enterprises consume the lowest cost during the process of gantry crane “fuel to electricity” to maximize economic benefit while contributing to society; at the same time, government enables enterprises and itself to obtain maximal benefits by paying the lowest cost during the process of promoting enterprise to implement gantry crane “fuel to electricity”, and then facilitate the sustainable development of port.

1.3 Methodology

By means of analyzing carbon emission status in domestic and overseas ports, and combining with national policy as well as strategic deployment of port carbon emission, this paper summarized the mainstream measured for reducing carbon emission both in China and other countries—gantry crane “fuel to electricity”. Most researches applied qualitative method while the calculation of port actual carbon emission is few. Thus, this paper carried out quantization on it. Starting with the viewpoint of full life cycle, it rendered CO_2 emission calculation model of traditional rubber-tyred gantry crane and the CO_2 emission of rubber-tyred gantry crane taking electric power as power in work unit. Besides, taking Dalian Port as example, it carried out empirical, compared and analyzed the results. Next, this paper narrated that, under the circumstance that government introduces carbon emission tax to negatively motivate enterprise gantry crane “fuel to electricity”, within certain planning period, the optimization model of gantry crane “fuel to electricity” was completed so that enterprise consume the lowest cost during gantry crane “fuel to electricity”; it conducted empirical verification on model by taking Dalian Port. Furthermore, during gantry crane “fuel to electricity”, it analyzed governmental subsidy policy and researched the promotion effect of different government subsidies on enterprise gantry crane “fuel to electricity”.

1.4 Outlines of the Dissertation

The rest of the dissertation is organized as follows:

Chapter 2, **literature Review**, overviews related researches, studies and reports on the port regulation, carbon emission calculation and carbon emission control at ports. **Chapter 3**, **status analysis of port carbon emission and emission reduction strategy**. After analyzing and comparing carbon emission status as well as management policy of domestic and overseas ports, this chapter selects the primary policy measure—in-depth research on gantry crane "fuel to electricity". **Chapter 4**, **carbon emission calculation model based on full life cycle**. By means of full life circle method, chapter 4 researches the carbon dioxide emission of traditional gantry crane and the gantry crane powered by electricity; it carries out comparative analysis of frame. Taking Dalian Port as example, it calculates and compares the carbon emission of rubber-tyred gantry crane "fuel to electricity". **Chapter 5**, **benefit analysis of gantry crane "Fuel to Electricity"**, sets up dynamic planning model of the gantry crane "fuel to electricity" process to guarantee that, within certain gantry crane "fuel to electricity" planning period, port obtains higher economic benefit at lower cost under the condition that government introduces carbon emission tax, so as to inspire initiative of implementing gantry crane "fuel to electricity" at port; in terms that government provides subsidy, it researches the electric gantry crane purchased by port and quantity of gantry crane "fuel to electricity"; if government fund permits, government may select superior financial subsidy policy in accordance with research results. **Chapter 6**, **Conclusions**. The summary of findings, implication and limitations of this study and practical recommendation will be presented.

Chapter 2 Literature Review

Many Chinese and foreign scholars have conducted studies in terms of port regulation, carbon emission calculation and carbon emission control at ports.

First of all, the study of port regulation can be further divided into two categories: general theories or framework, and empirical studies on the administration and governance of certain countries or regions.

Next, scholars are currently proposing measures regarding the construction and development of low-carbon ports with qualitative methods through analyzing the low-carbon development experiences of Chinese and foreign ports as well as the situations and shortcomings of the low-carbon construction of Chinese ports. However, the study achievements concerning actual carbon emission calculation of ports are few.

Last but not least, there are two main sources of port carbon emission: port users and port equipment. There are many studies and literature on carbon emission control starting from these two aspects.

2.1 Port Regulation

2.1.1 General Theories or Framework

Notteboom, T. (2007) pointed out that in policy-making, special attention should be given to the overall strategy of low carbon development, the research and application of low carbon technologies, the upgrading of infrastructure and transport facilities, so as to guide supporting policies concerning low carbon selection, investment and financing, energy-saving and emission reduction industry as well as market development. Secondly, in system construction, the building of supervision capability on energy-saving and emission reduction of ports should be paid sufficient attention, realizing standardized management. Thirdly, the assessment system used for the analysis and evaluation of the construction progress of low carbon port system shall be established.

Hu Hongjun (2012) overviewed the low-carbon development status of Chinese ports and the challenges faced by Chinese ports in development, and ultimately proposed specific measures and suggestions regarding the development of low carbon economy at Chinese ports.

Tian Yuma (2016) described that in terms of development priorities, the construction of low carbon ports in Zhejiang province is in need of powerful scientific support and government policy guarantee. The strength of science shall be fully utilized to play its foundation role in the development of low-carbon ports, and the use of new energies and renewable energies, such as wind and solar energies, shall be actively promoted. Besides, the new technologies in energy-saving and emission reduction shall be actively utilized, and the all-round innovation in ideas, policies, systems and technologies shall be facilitated.

Zhao Yaqian (2015) proposed that building green low-carbon ports is the only route which must be passed. During the process of energy-saving and emission-reduction construction of ports, many factors, such as, construction cost, reduced amount of emission, energy-saving effects and economic benefits, have to be taken into consideration. Therefore, each port shall choose its own energy-saving and emission reduction combination scheme according to its own conditions, and reasonably arrange the sequence of construction. Multi-objective optimization shall be applied into the energy-saving and emission reduction of ports, while economic and environmental benefits have to be taken into comprehensive consideration, so do restraining conditions like construction cost, schedule and control indexes of energy-saving and emission reduction. Besides, a multi-objective 0-1 planning model for the energy-saving and emission reduction of green ports shall be constructed, and the planning function of Excel shall be used for model optimization, confirming energy-saving and emission reduction projects and their schedule in a scientific manner. In addition, the energy-saving and emission reduction project of ports in Jiangsu was used for empirical analysis, obtaining an optimized plan of such a project. The optimized plan provides an emission reduction rate of 38.4%, which is of obvious effects, proving the feasibility of the model.

2.1.2 Empirical Studies on the Administration of Certain Regions

On the basis of the conditions of the port construction in Zhejiang province, Tian Yuma (2016) mentioned that energy-saving and emission reduction technologies shall be actively adopted in low carbon port construction, because the technological improvement serves as the key path to realize energy-saving and emission reduction at ports. All port enterprises are dedicated in solving energy-saving and emission reduction as well as pollution prevention projects through technological breakthrough, and improving port productivity with technological innovation and progress. Multiple energy-saving technological improvement projects, such as LNG vehicle dispatching at port and port power supply project, are implemented and completed.

In respect to green port construction, the main measures taken by the Ministry of Maritime Affairs & Fisheries of Korea (previously known as the Ministry of Land, Transport and Maritime Affairs) include: 1) Changing traffic means, actively developing railway and waterway combined transportation of containers, promoting the shift from roadway transportation to coastal transportation, for example, an 18km canal built between Seoul and Inchon, that is, "Seoul-Inchon Channel" which connects Han River and the Yellow Sea; 2) encouraging the use of renewable energy sources, such as wind and solar energies, building wind and solar power generation facilities within the port, for example, the wind driven generators built in the logistics park of Inchon Port; 3) actively promoting the application of port low-carbon technologies, such as wharf and vessel shore power technology, "fuel-to-electricity" shift for port loading/unloading facilities, and the use of energy-saving lamps for port lighting.

In recent years, Japan takes the "greenization of port administration and management" as the fundamental basis of port policies, in which ports will play their role in logistics, industry and the construction of living quarters, promoting sustainable development. A management system that involves authorities, research institutes and civilians is built. As one of the typical large green ports in Japan, Sakai Port centers on a low-carbon culture and conducts a variety of practices, such as the establishment of civil environmental culture archives, rewarding civilians and port operators who have made significant contributions to the low-carbon construction of the port, so as to make full use of the wisdom of the masses to promote the port's low-carbon construction. With the shift in industry structure, reform of city structure, and creation of environmental culture among civilians, the emission of greenhouse gases of Sakai Port is expected to reduce by 15% in 2030 compared with that of 2005, and 60% in 2050.

Xu Sheng and Ma Yanmin (2013) elaborated the positive effects of rubber-tired gantry cranes' "fuel-to-electricity" shift in Shenzhen Yantian Port on environment, illustrating the environmental influence brought about by the "fuel-to-power" shift, so as to promote the "fuel-to-electricity" shift for rubber-tired gantry cranes in other ports of Shenzhen city.

2.2 Carbon Emission Calculation

2.2.1 Methods on Carbon Emission Calculation

According to the history data and industrial features of Chinese ports, Men Lianhuan (2014) predicated the port handling capability along the coast using the GM (1, 1) grey forecasting model, and then forecasted the unit consumption of standard coal and carbon emission based on the relationship between port handling capability and energy consumption. The result showed that the carbon emission at major Chinese ports will witness a rapid growth by 2050. In view of this, suggestions were proposed in respect to the construction of a green port assessment index system, the application of environmental protection law system, the perfection of port green information system, the implementation of environmental incentive mechanism, and technological innovation.

Javanshir, H. (2010) argued that gantry crane was an important port resource in containers handling. Therefore, how to reasonably schedule rubber-tired gantry cranes is significant for the reduction of port carbon emission and operational cost. In consideration of the fact that rubber-tired gantry cranes has no spanning possibility and other limitations, a mixed integer programming model of rubber-tired gantry cranes scheduling was established based on the carbon emissions generated from their movement, loading/unloading and preparation, with a view to minimizing the carbon emission of gantry cranes. Due to the complexity of mixed integer programming solution, an initial path strategy was designed and solved a near-optimal solution with simulated annealing algorithm. With computation examples, the effects of the new method were assessed from the aspects of path length, total carbon emission and operational efficiency. The path length in the new method increases by 8.82% in comparison with the shortest path optimization method, and the operating time only increases 0.21s, while the total carbon emission reduces by 3.30%. Under the premise of guaranteeing the working efficiency of gantry cranes, their low carbon path problem is effectively solved. In comparison with classic genetic algorithm and ant colony algorithm, the forecasting precision of the new method proposed increases by 1.13% and 2.24% respectively, while its operating efficiency increases by 9.82% and 5.92% respectively.

Luo Junhao (2014) evaluated the environmental efficiency of 8 container ports in China from 2005 to 2011 using SMB-DEA model. The annual CO_2 emission of each port was set as the undesirable output to analyze the influence of CO_2 emission on efficiency. The analysis results showed that the carbon emission of each container port imposed an adverse influence upon its efficiency. The environmental efficiency assessment models of 8 container ports showed a rise from 0.476 to 0.764. All 8 ports have shown non-efficiency to varying degrees from 2005 to 2011, and the reasons behind the non-efficiency lie in too many investment factors of ports, insufficient investment compared with container handling capability and excessive emission of carbon dioxide. Besides, the global financial crisis of 2008 also brought negative effects on the efficiency of 2009.

Peng Chuansheng (2012) used the 2010 Carbon Footprint of Jurong Port, Singapore as an example to calculate the carbon emission of the port.

(1) The CO_2 emission generated by power consumption in the calculation period can be calculated with the following equation:

Where, EE refers to the CO_2 emission (t) caused by power consumption during the calculation period;

n: The number of emission sources of power consumption;

I: The ordinal number of emission sources of power consumption;

CEi: The power consumption of the i^{th} emission source (kwh) during the verification period;

FE: CO_2 emission factor ($kgCO_2$/kwh) of the power consumed by the port,

There are some differences due to different power sources. According to the statistics of Singapore, the CO_2 emission factor of power at Jurong Port is defined as 0.5016 $kgCO_2$ / kwh.

(2) The CO_2 emission generated by fuel consumption in the calculation period can be calculated with the following equation:

Where, EF is the direct CO_2 emission (t) caused by fuel consumption during the calculation period;

n: The number of emission sources of port fuel consumption;

I: The ordinal number of emission sources of port fuel consumption;

CFi: The fuel consumption of the i^{th} emission source (L) during the verification period;

FFi: The emission factor ($kgCO_2/kwh$) of the i^{th} emission source,

The emission factors of different fuels are calculated based on their calorific values, CO_2 emission and proportion per unit calorific value. If there is no CO_2 emission per unit calorific value, the default value of CO_2 emission per unit calorific value of the corresponding fuel can be selected in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories published by the Intergovernmental Panel on Climate Change. The emission factors of diesel and gasoline at Jurong Port are $2.647kgCO_2/L$ and $2.318kgCO_2/L$.

2.2.2 Effect on Carbon Emission Calculation

RobinMacod (2010) established a calculation model for the carbon emission of the coal-power chain in China with the method of full life circle assessment, and the result showed that coal-fired generation is the main part of carbon emission. This research is of great significance for determining the carbon emission sources in coal-power chain and the carbon dioxide emissions of various sources, reducing carbon dioxide emission during coal-fired generation, and realizing the sustainable development of power industry.

Laurence Jones (2011), with a reference to the list of greenhouse gases emission and based on the status quo of China’s energy consumption, categorized the calculation methods of urban energy carbon emission into three types, and verified them by taking Beijing as an example. The research discovered that the calculation method of energy consumption imposes a great influence upon calculation results. They also analyzed the reasons for generating uncertainties, and proposed that a more detailed carbon emission calculation system is needed in order to meet the demands for calculating carbon emission in today's national economy.

Rik Thomas (2011) proposed to verify the carbon emission of buildings by creating models with the life circle method, and verified models with case studies. They then proposed some measures regarding the reduction of building carbon emission based on the verification results.

2.3 Carbon Emission Control

There are many studies on the vessels and land vehicles emissions (Villalba and Gemechu, 2011; Lee et al., 2014; Song, 2014; Tichavska and Tovar, 2015) and the social or external costs of emission (Berechman and Tseng, 2012; Chatzinikolaou et al., 2015; Maragkogianni and Papaefthimiou, 2015).

Wang Qian (2016) wrote in her paper regarding the measurement of carbon emission and low carbon development strategies of Ningbo Port that greenhouse gas protocol defined three ranges in calculating corporate carbon emission: the first is the emissions directly generated by corporate productions, which mainly refers to the emission of fossil fuel consumption; the second is the indirect emissions generated by the power consumption of corporate productions; and the third is other indirect emissions except for the above mentioned. This paper mainly calculates the port carbon emission based on the fuel consumption, power consumption and vessel activities, and different calculation ranges include the following:

(1) Consumption of fuels, including the fuels consumed by gantry cranes (gantry and cantilever), traditional rubber-tired gantry cranes, forklifts as well as vehicles, such as trucks and trailers, but excluding the fuels consumed by vessel power generation and operation. Besides, fuel consumption at port mainly consumes diesel, whereas gasoline is barely used. Based on the data collected, the calculation for CO_2 emission is mainly focused on that produced by diesel consumption at port.

(2) Consumption of power, including the power consumed by production equipment, such as electric rubber-tired cranes, transporter cranes, and quayside container cranes; facilities and spaces, such as lighting, office buildings, warehouses, stuffing and destuffing space, and operating area; operations, such as mechanical maintenance, sewage treatment, ventilation and vehicle inspection and weighing; and equipment and installations for the daily management and operation of the port.

(3) Vessel activities. The emission includes carbon dioxide emission generated by the fuel-based power generation when vessels are waiting, loading and unloading. Even though Ningbo Port has been promoting the use of shore power in recent years, only few vessels are using shore power, and most vessels are operating with the power generated by consuming their fuels. Therefore, the cases where shore power is used are excluded.

Bill Mongelluzzo (2010) said that Long Beach Containers Port has carried out energy-saving measures towards three major carbon emission sources – transtainers, trailers and vessels – through multiple technical transformations. The projects, such as “fuel-to-electricity shift for transtainers”, “auxiliary generators for transtainers” and “hybrid power energy-saving experiment for transtainers”, have achieved significant results. “Vessel shore power supply” project now saves approximately 7 tons of fuel per day for each medium-sized vessel, reducing 0.19 tons of sulfur dioxide and 0.11 tons of oxynitrides.

Hong Shan et al. (2006) introduced the main technological plan, features and energy-saving technology development in the “fuel-to-electricity” shift for rubber-tired gantry cranes in China and other countries, and profoundly analyzed the energy-saving technologies adopted in the “fuel-to-electricity” shift process for rubber-tired gantry cranes.

Many studies also consider the port emission issue from cargo-handling activities (e.g., van Duin and Geerlings, 2012; Zheng et al, 2016).

Chapter 3 Status Analysis of Port Carbon Emission Reduction Strategy

3.1 Analysis on the Development Strategy of Low-Carbon Ports

1. In constructing our low-carbon port, the first step is to establish low-carbon emission standard. Lacking scientific and rational standard as a guideline in constructing low-carbon ports, the enterprises participating in port activities will lack modification purposes of emission reduction. So we can refer to foreign ports and combine with our practical situations, so as to establish assessment system of low-carbon port standards. For instance, setting emission standards on marine vessels, port vessels, and container trailers and handling equipment, constructing low-carbon ports according to the laws.

2. Restructuring energy consumption

The purpose of restructuring energy consumption is to reduce carbon emission and realize low-carbon development. For a long time, coals have accounted for over 65% of primary energy consumption in our ports. The major problems of coal consumption include low combustion efficiency and serious environmental pollution. Now, China has been the second largest oil consumer. As predicted, our independence to imported oil will reach to 60% till 2029. Our port is improving energy consumption structure, especially increasing the utilization efficiency of coal through the comprehensive utilization and clean utilization of coal and meanwhile further optimizing secondary energy structure.

3. Developing clean energy and introducing low-carbon technologies

Clean energy should be used rather than diesel power operating system. Diesel power operating system creates typically high energy consumption and pollution. For instance, ocean vessels are only allowed to utilize alternative fuels; container truck can adopt clean electricity truck and liquefied natural gas trucks like the US; as for the ports in living areas, we can actively utilize and develop advantageous resources of wind power; to establish electric transport system at the ports; further utilize solar power and other clean energies. Besides, introducing foreign advanced technological equipment, utilizing “shore power” can facilitate the transformation to low-carbon ports. Strengthening pollution emission surveillance and energy-saving and emission reduction management is mainly through the relevant monitoring technologies to explore pollutant emission and carrying out investigations at fixed period.

3.2 Government Strategy of Port Carbon Emission Reduction

3.2.1 Strategy of Port Carbon Emission Reduction in China

Chinese ports mainly realize low-carbon development through energy conservation and emission reduction. They adopt a new development mode of government supervision and management, and enterprises independent innovation, through technological development and systemic innovation, so as to realize low carbon economy of the ports. During developing low-carbon economy of ports, Shanghai Port is in the forefront of national ports, which has endeavored to build a new image as a green and low-carbon port and build an international shipping center and financial center in Shanghai. Shanghai Port has carried out a planning research on constructing a green port and adopted new technological devices of energy conservation and emission reduction. In July, 2010, Shanghai Port and China Shipping Group jointly issued a declaration on building green water transport together, launched shore-based marine power supply system. China’s first mobile port shore-based marine variable voltage variable frequency power supply system was put into operation. Port shore-based power replacing shipping fuel power supply can reduce the carbon emission of the port, so as to achieve the development goal of green port. The third phase of Yangshan was allocated with 71 hybrid power RTG. According to relevant data, introducing the technology across China can reduce the emission of CO_2 by 9.17 million tons effectively.

Since 2006, Tianjin Port has started to utilize container rail-mounted gantry cranes to save standard coal by 12.9 thousand tons in three years; on this basis, container rubber-tired gantry crane “Fuel to electricity” project can save standard coal by 13.1 thousand tons; meanwhile, Tianjin Port has promoted and applied the PLC variable-frequency regulating speed technology, both effectively reducing energy consumption and realizing the improvement of technological level and content of handling equipment of the port. At the same time of carrying out transformation of energy-saving technology, Tianjin Port has constantly increased the input in the researches and promoted the technological progress. Over thirty researches and application of energy-saving projects have been accomplished including “innovative technologies research and application of clean renewable energy in Tianjin Port area”. Now, Tianjin Port Free Trade Zone has formed seven major low-carbon industry clusters, gathering numerous environmental and energy-conservative enterprises, primarily shaping a sophisticated and high-ended development pattern of green low-carbon industry.

Port of Qingdao has opened “era by second” of productive efficiency, promoted the economic structure, advanced the low-carbon and ecological economy, maximized the resources conservation, achieving brilliant results. Since the fifth National People’s Congress in China, the annual handling capacity of the port has increased by nearly three times, while the comprehensive energy unit consumption has dropped by 29.7%, and 4.1% annually, realizing a balance between port development and environmental protection. Meanwhile, Port of Qingdao has carried out process technological reform on ore terminal, reducing ores by 7.2 million tons, oil by 792 thousand liters, carbon dioxide by 2,074 tons, and expenditure by 12,356 million yuan. Through "Fuel to electricity", the consumption per container was dropped by over 40% and the costs per container was decreased by over 70%, realizing the zero consumption of waste gas. The technology has been applied in over 200 devices of over a dozen ports in China and abroad, reducing oil consumption by 20 million liters with great economic and social benefits.

3.2.2 Strategy of Port Carbon Emission Reduction in other Countries

Table 1 - Low Carbon Methods Adopted by Foreign Ports

Name of Port	Purpose or Influence	Methods or Characteristics
Long Beach Port	Controlling emission of vessels berthed in port; reducing 80% of emission within 5 years	"shore power"; utilization of replaceable fossil fuel at lower speed nearby port
Port of Los Angeles	Starting using first batch of 20 sets of LNG heavy trucks; "clean truck project"	Truck uses clean fuel to replace diesel
Venetian Port	Reducing 30% of CO2 and 95% of NO emission during vessel docking; greatly lowering noise	"shore power"; constructing electronic traffic system; using solar energy, wind energy, and low-sulphur fuel
New York Port	Reducing congestion and constructing green low-carbon port	Constructing port environmental system and expanding high-speed rail
Sydney Port	Reducing port emission and enhancing air quality	Replacing highway with railway

Source: Own presentation

The emission of Long Beach Port is the main cause for air pollution. It has adopted some measures to control the emission of vessels at anchor. For instance, adopting "shore power" replaces auxiliary power supply to drop anchor, and adopting "Green flag project" awards vessels in low speed near the ports. Venetian Port of Italy has launched "shore power" system to reduce the pollution during anchor. The Port Authority of New York and New Jersey establishing green low-carbon port is through establishing port environment management system.

Meanwhile, port authority strengthens the internal practices, reduces the traffic pollution by improving infrastructures, and emphasizing sustainable development.

3.2.3 Main Practical Measure of Port Carbon Emission Strategy-- Gantry Crane "Fuel to Electricity"

Besides, ports of Lianyungang, Shekou, Wuhan and Dalian also have applied the marine shore power station technology, energy saving and emission reduction technology of port marine power supply system, "Fuel to Electricity" technology, scoring both economic and social benefits.

Table 2 - Low Carbon Methods Adopted by Domestic Ports

Name of Port	Measures	Effects
Qingdao	"Fuel to electricity", energy saving technology	Each TEU energy consumption decreased by 39.7%
Yantian Port	"Fuel to electricity"; modified wharf crane control circuit; adopted solar energy; sea-railway combined transportation	Avoided energy waste; realized 100% of forklift smoke detection passing rate
Caofeidian Port	Energy saving; use of fully automated container wharf	Reduced 16% of carbon dioxide emission
Tianjin Port	"Fuel to electricity"	Replaced petroleum with electricity and reduced 4.9% of energy consumption

Source: Own presentation

Chapter 4 Carbon Emission Calculation Model Based on Full Life Cycle

4.1 Carbon Emission Calculation Method

There are mainly 6 methods of carbon emission calculations in China and foreign countries, including measuring, material measuring, emission coefficient, modeling, life cycle and decision tree.

Measuring method refers to supervised detection, measuring the flow rate, flow velocity and concentration of waste water and gases with detection methods or nationally approved continuous measuring instruments before statistics and calculation of results.

Material measuring method is a scientifically effective calculation method which is based on the conservation of mass principle, as in the mass of the materials being put into the system equals the mass of the materials being output by the system, carrying out profound studies of the materials being used in production process, the production of emissions as well as the disposal system.

Emission coefficient method is a calculation method which calculates the emissions of a certain material through estimating the multiplication between the emission coefficient and the energy consumption under regulation technical, economic and managerial conditions.

Modeling method refers to a method for the estimation of complex ecosystems, social systems and energies, and industrial carbon emission where the carbon emission are affected by various factors such as seasons, terrains, climate, economic development, energy structure, and technical level and such factors are interacting among themselves.

Full life cycle assessment method refers to the method for the assessment of certain material from its appearance and perishing as well as the following effects after its perishing, which is an objective process that assesses the environmental load related to products, techniques or behaviors. It assesses the effects of energies and material use and environmental emission through recognizing and quantifying them, and it assesses and implements the opportunities that affect environmental improvement. The assessment involves the entire life cycle of products, techniques or behaviors which include the extraction and processing, production, transport and delivery, use, reuse and maintenance, recycling and final disposal of raw materials.

Decision tree method is a way to estimate the carbon dioxide emissions of complicated carbon sources, which forms a tree diagram for the sources that generate carbon emissions. Tracing from the trunk, those main carbon sources can be fixed and then those sources beneath major carbon sources as the process goes down. When all major carbon sources and relevant carbon sources are found, it starts from the beginning of decision tree again to locate all less important carbon sources and relevant sources, until all carbon sources are located.

Each and every calculation method described above has its own advantages and applicable range. The carbon emissions of the extra powers of the “oil-to-electricity” gantry cranes are verified in this dissertation. Full life cycle is adopted in this dissertation for the verification of the carbon prints of “oil-to-electricity” gantry cranes since there are more steps that generate carbon emissions involved in coal-electricity energy chain and the use of petroleum.

4.2 Technical Framework of Full Life Cycle

The definition of objective and scope, inventory analysis, impact assessment and improvement assessment are four interconnected components of the technical framework of full life cycle assessment, which were proposed by Society for Environmental Toxicology and Chemistry (SETAC) in 1993.

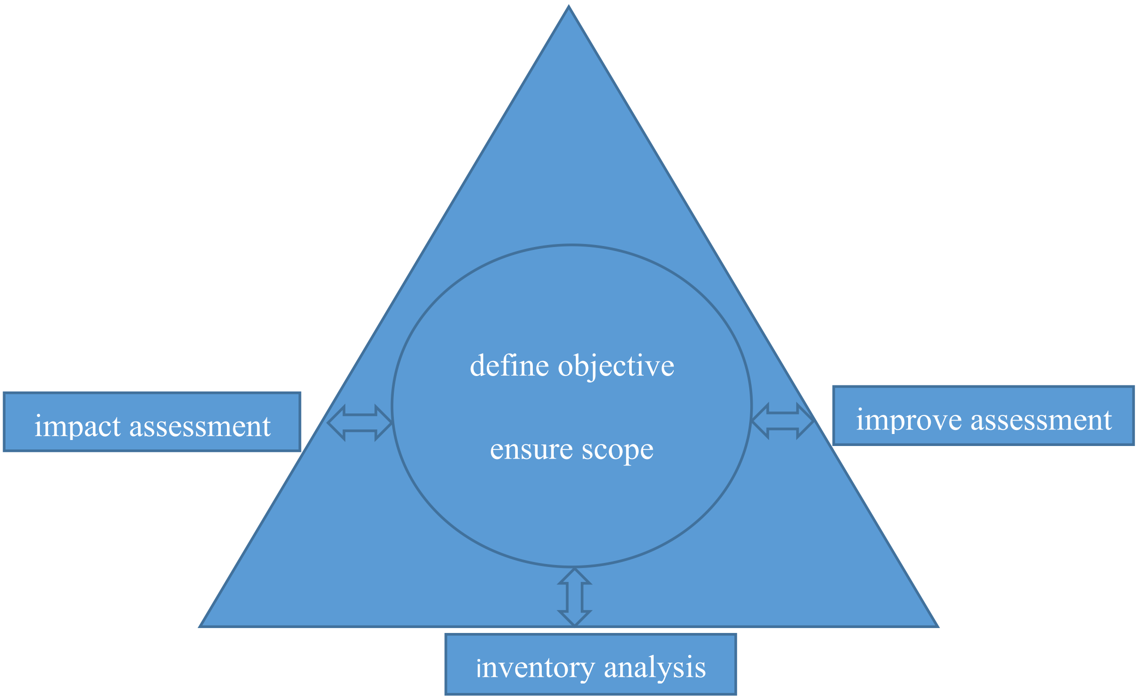

Figure 1 - SETAC Full Life Cycle of Technical Framework

Source: Environmental Toxicology and Chemistry (SETAC)

The ISO14040 standards issued in 1997 have made some changes to the original technical framework. So the content of the technical framework is more abundant.

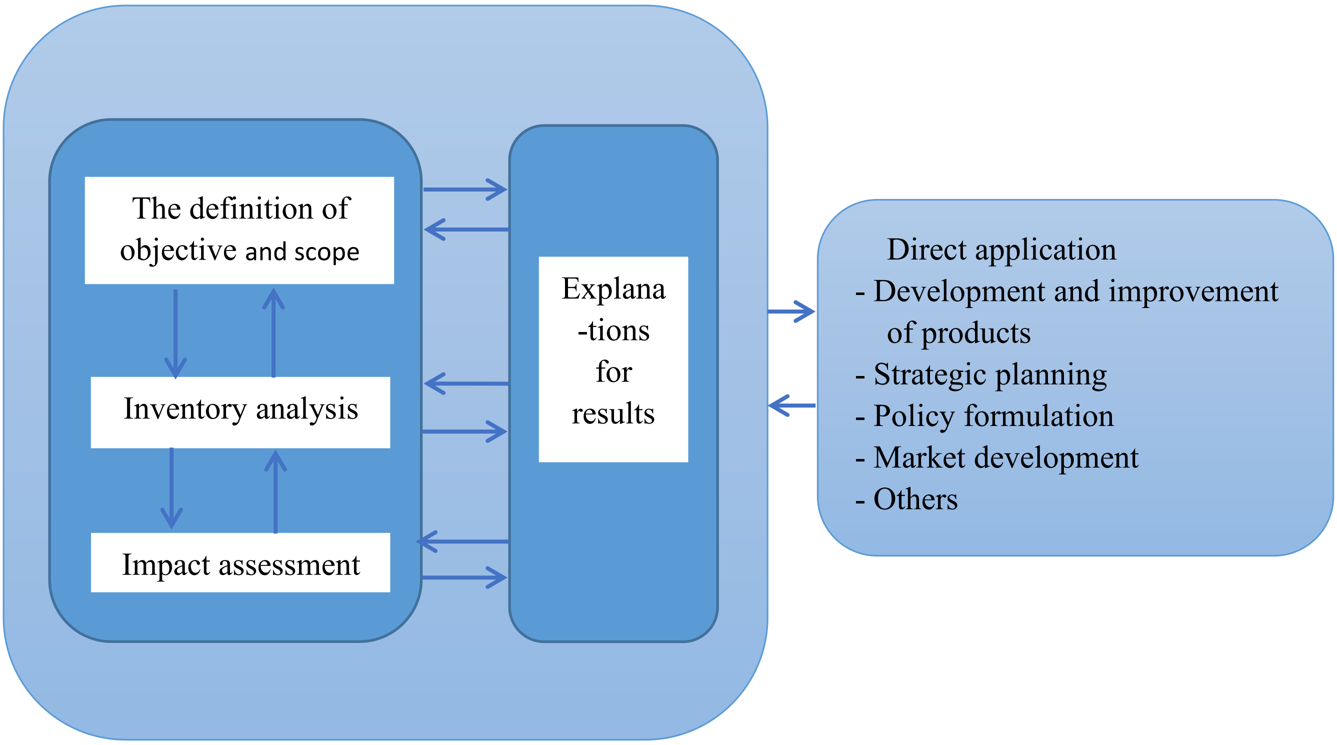

Figure 2 - ISO Full life Cycle of Technical Framework

Source: ISO14040

4.2.1 The Definition of Objective and Scope

The study on the definition of objective and scope serves as the first stage of full life cycle assessment. Study objective refers to the definition of the reasons of the study and the application of study results. The study scope is consequently defined once the objective is defined. We may define the study range with system functions, system boundary, environmental impact type and data demands, ensuring the width, depth and details of the study in order to ensure the final realization of the study objective.

(1) System and system boundary

Internal system and system environment constitute a complete system, including the entire process starting from the excavation of raw materials to the final disposal of waste. We illustrate it with an example in the following figure:

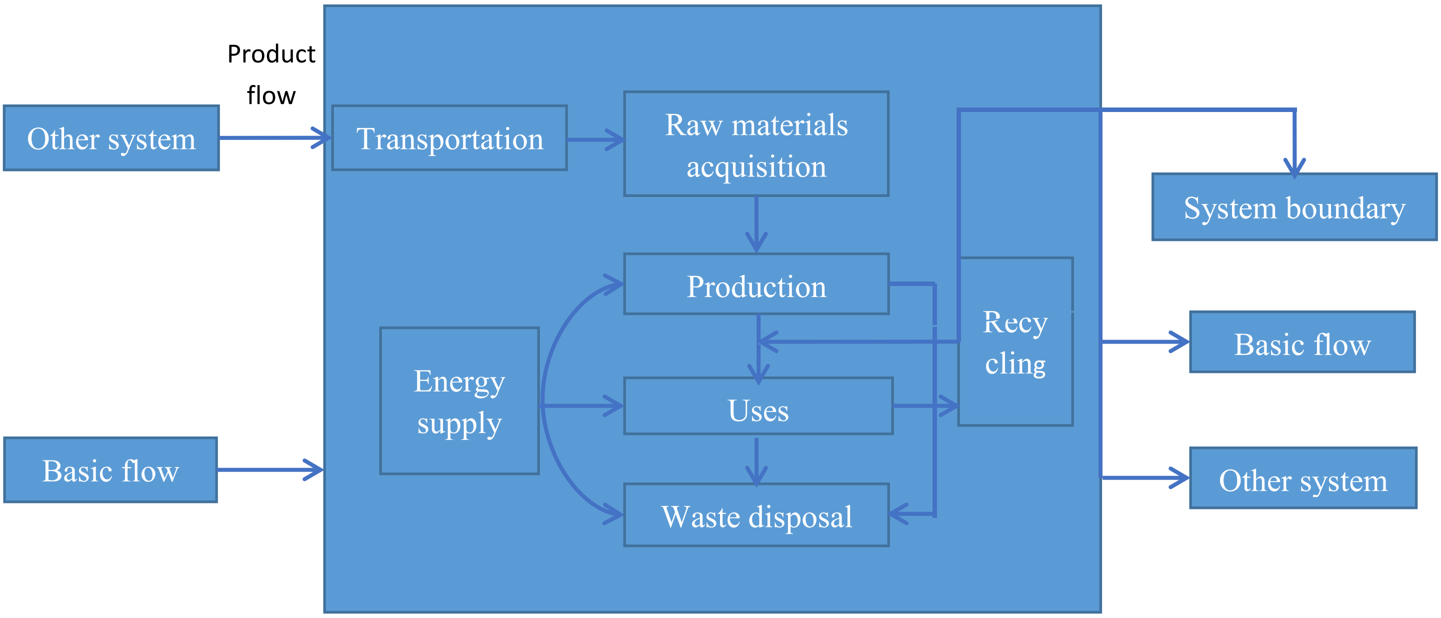

Figure 3 - Product System Sample

Source: Environment system

(2) Functional unit

Functional units are the foundation of full life cycle assessment. All data collected through the full life cycle assessment shall be transformed into functional units for it is the quantification of functional attributes, and decided by product functions.

(3) Data quality

Data quality determines the results of full life cycle assessment, the quality of data and time span, space range, and it is closely related to technical level. We shall illustrate the sources of the data measured and the data from literature while employing full life cycle assessment.

4.2.2 Inventory Analysis

Full life cycle inventory analysis is the process where all inputs and outputs throughout the entire life cycle are compiled and quantified, including the consumption of energy and resources by products, production or techniques throughout the entire life cycle as well as the quantification of emissions. Inventory analysis serves as the primary basis of the effects imposed by products, production or techniques on environment.

The main reason why we carried out inventory analysis lies in data collection. A standardized method for inventory analysis is yet to be formed, and the simplification of inventory analysis is demonstrated in the following figure:

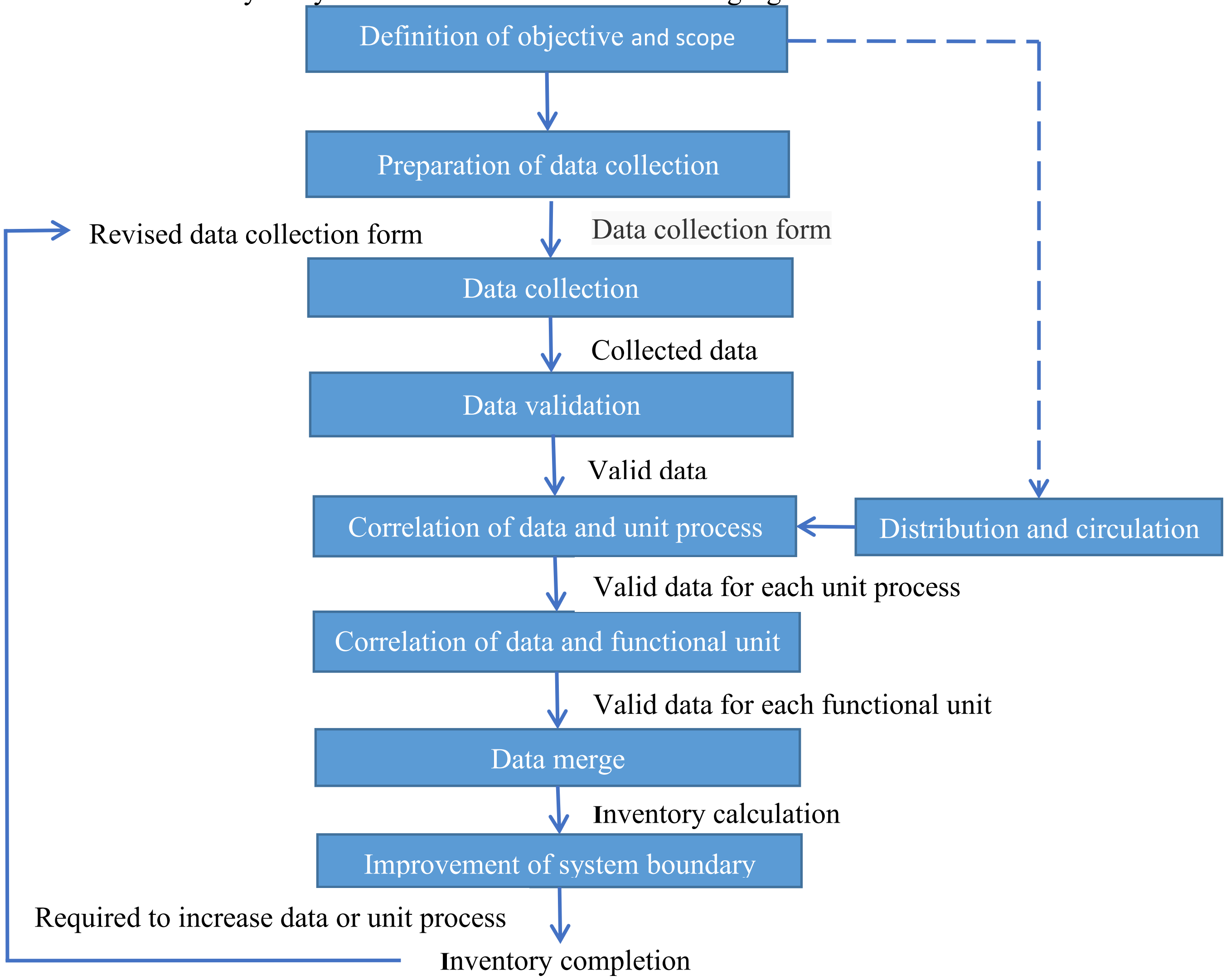

Figure 4 - The Simplified Procedure of Analysis List

Source: The standardized method

4.2.3 Life Cycle Interpretation

Life cycle interpretation provides easily understandable explanations for the results of full life cycle assessment and defined objective and scope. It is a process that analyzes the results of the studies on the previous stages of life cycle or the result of inventory analysis, and draws a conclusion or explains the limitations of results.

Recognition, assessment and report are three major components of full life cycle, which are concluded according to the criteria specified in ISO 14043. Life cycle interpretation is very much closely related to other stages of full life cycle assessment, as shown in the following figure:

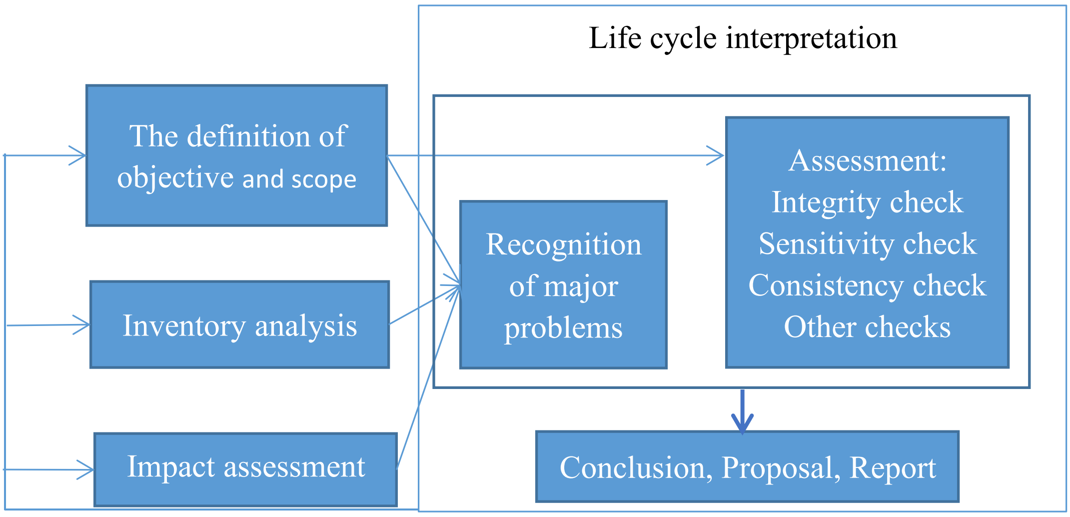

Figure 5 - The Relationship between Life Cycle Interpretation and Other Life Cycle Phase

Source: ISO 14043

4.3 Objective and Scope

Whenever we want to compare the carbon dioxide emissions generated from the energy consumption of diesel-driven rubber-tired gantry cranes and electricity-driven Rubber-tired gantry cranes from the perspective of full life cycle, we shall consider it starting from the analysis of the fuel's life cycle. It includes three processes which are raw materials, fuels and the operation of rubber-tired gantry crane. The life cycle assessment of the fuels burned by rubber-tired gantry crane (RTG) is the assessment boundary, including the entire fuel life cycle starting from primary energy exploitation to the use of RTG. It includes two primary stages: the production and distribution of fuel, and the use of fuel. The production and distribution of fuel includes: the exploitation and transport of fuel, the processing and distribution of fuel, which are called as the upstream of the life cycle assessment; the use of fuel refers to the operation of RTG, called as the downstream of the life cycle assessment, as shown in the figure. Both the upstream and downstream make up the entire life cycle, which is the definition of the system scope. The external environment of the system is consisted of substances, energy, and greenhouse gas emission, among which substances, energy and capital are the inputs to the system, while greenhouse gas emission is the output from the system.

As shown in the figure:

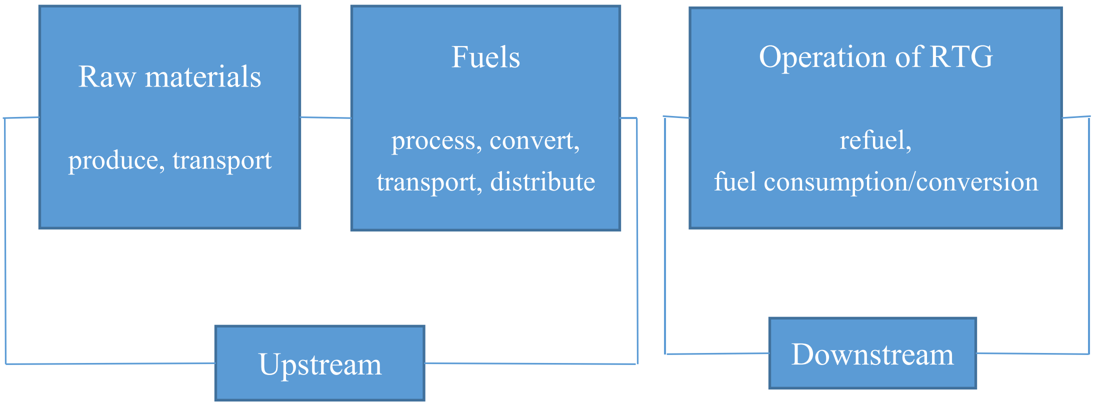

Figure 6 - Defining the Scope of the System

Source: Own presentation

4.4 Full Life Cycle Carbon Emission Calculation Model of Rubber-tyred Gantry Crane "Fuel to Electricity"

4.4.1 Full Life Cycle Carbon Emission Calculation Model of Fuel-Driven Rubber-tyred Gantry Crane

1. Objective and scope of full life cycle carbon emission calculation model of fuel-driven RTG

The full life cycle assessment of fuel-driven RTG includes the exploitation, transport, processing of petroleum, the transport of diesel and the operation of RTG. The exploitation, transport, processing of petroleum, and the transport of diesel constitute the upstream of fuel life cycle assessment; while the operation of RTG constitutes the downstream of fuel life cycle assessment. The external environment of the system is consisted of substances, energy, and greenhouse gas emission, among which substances, energy and capital are the inputs to the system, while greenhouse gas emission is the output from the system. As shown in Figure 7:

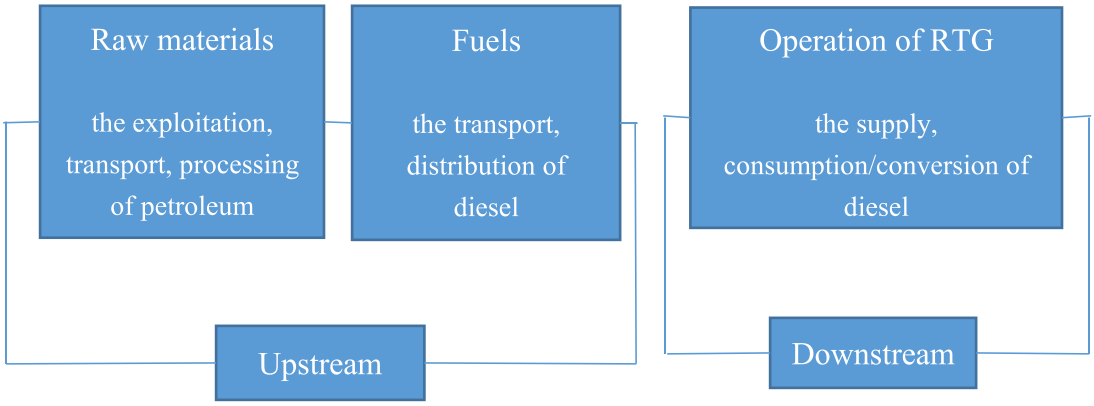

Figure 7 - Traditional Gantry Crane Calculation Scope in Full Life Cycle

Source: Own presentation

2. Carbon emission calculation model of upstream stage

The upstream stage of the full life cycle carbon emission calculation of fuel -driven RTG can be further elaborated according to its specific chain of operations and procedures, as shown in Figure 8:

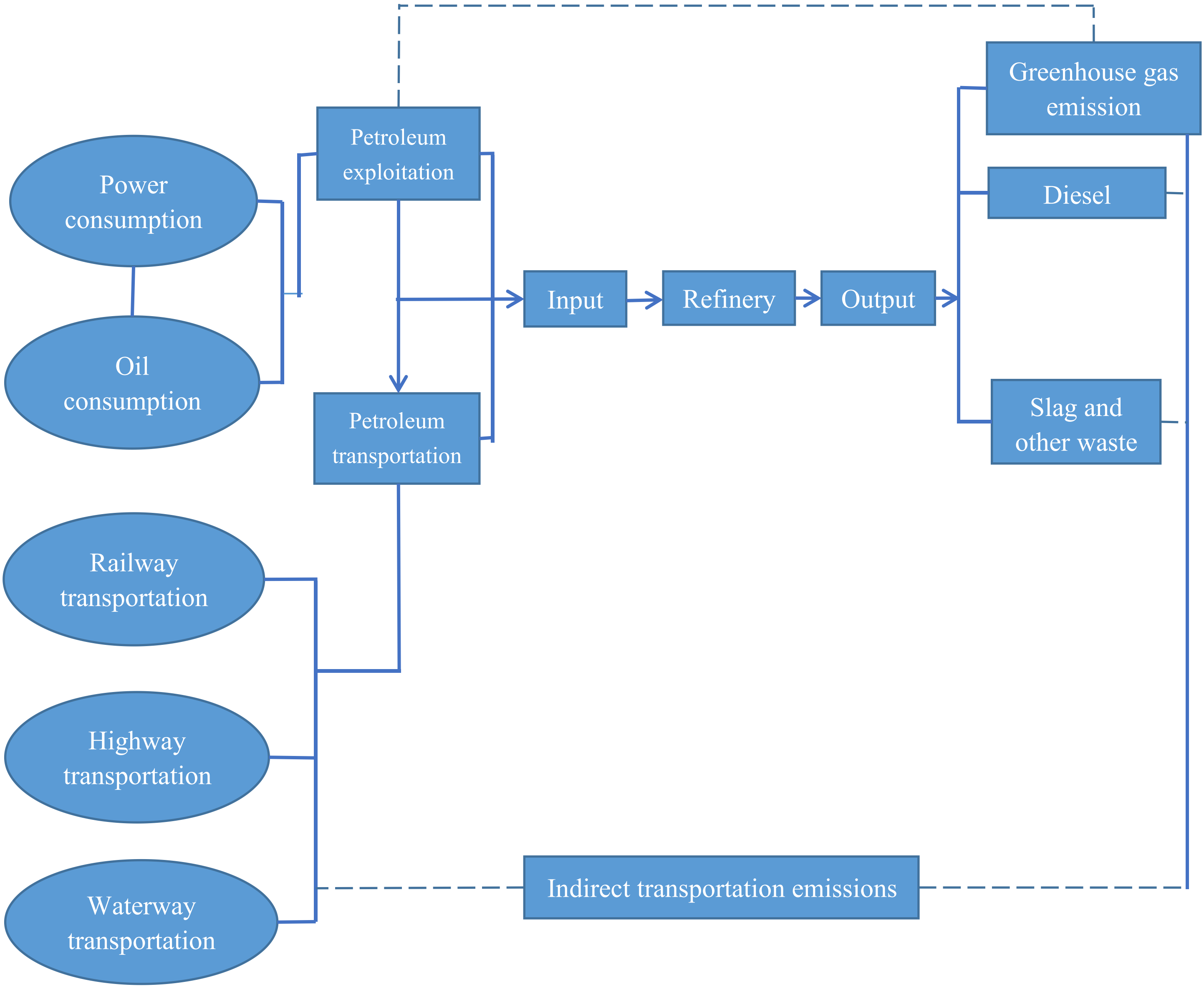

Figure 8 - Carbon Emissions Measurement Rage of Traditional Gantry Crane Upstream Phase

Source: Own presentation

(1) To calculate the carbon dioxide emission generated in the upstream stage of fuel-driven RTG, the required petroleum production of diesel consumption per unit

time period for RTG operation shall be confirmed, as required by principle of diesel transformation. Relevant data of China Statistical Yearbook and China Energy Statistical Yearbook demonstrate that the efficiency of gasoline is 89.1%, the efficiency of diesel is 89.7% and the efficiency of residual oil is 94% during petroleum refining.

The calculation equation of the required petroleum production of diesel consumption per unit time period for RTG operation is as follows:

$$Q_{Oc} = a * B \tag{4-1}$$

$$Q_{Os} = \frac{Q_{Oc}}{T_{Oc}} \tag{4-2}$$

In the equation, t is the diesel consumption per unit time period for the operation of the RTG, Q_{Oc}; B is the quantity of standard containers operated by gantry cranes in the container terminal; a is the diesel consumption t per standard container, and Q_{Os} is the petroleum production t; T_{Oc} is the production efficiency of diesel, %;

(2) Petroleum exploitation

Petroleum exploitation includes prospecting and well drilling. When a potential oilfield is discovered, the first thing that needs to do is make exploratory drilling to determine whether petroleum exists or not. During the process, works such as land cleanup and level-up will be conducted for the convenience of drilling platform building and accessory equipment installation etc., all of which involve the emission of greenhouse gases. Meanwhile, greenhouse gases will be emitted during the drilling processes such as driving the diesel engine and turbine of the drilling equipment.

Table 3 - Various Energy Consumption for Oil Exploration Stage

Owner-occupied rate of the crude oil produced in the oilfield, %	Unit power consumption for crude oil production, Kwh/t
2.03	141.69

Source: China Energy Statistical Yearbook

The carbon emission coefficients of different forms of fossil energies are obtained according to the calculation methods issued by Intergovernmental Panel on Climate Change (IPCC) in 2006 in combination of the calorific values of different primary energies provided by China Energy Statistical Yearbook, as shown in Table 4.

Table 4 - Fossil Energy Carbon Emissions Coefficient Table

Energy form	Carbon dioxide emission coefficient
Raw coal	1.98kg CO_2/kg
Fuel coal	2.53kg CO_2/kg
Crude oil	2.76kg CO_2/L
Gasoline	2.26kg CO_2/L
Diesel oil	3.06kg CO_2/kg
Natural gas	2.19kg CO_2/M^3
Electricity	1.98kg CO_2/kwh

Source: Intergovernmental Panel on Climate Change (IPCC)

The carbon dioxide emission calculation model during petroleum exploitation stage:

$$C_1=Q_{Oc}\,(P_1*A_1+P_2*A_2) \qquad (4\text{-}3)$$

Among which, C_1 is the total carbon dioxide emission quantity (*kg*) during the petroleum exploitation stage; Q_{Oc} is the quantity of petroleum exploitation (*t*); P_1 is the carbon emission factor of crude oil; P_2 is the emission factor of power; A_1 is the owner-occupied rate of the crude oil produced in the oilfield (*%*); and A_2 is the unit power consumption for crude oil production (*kwh/t*).

(3) Petroleum transport

The storage and transport of petroleum are necessary links in petroleum production and they go throughout the entire process. The littering and leakage rate is assumed as 0 in this paper since leakage accident rarely occurs during petroleum transport, that is, the volume of crude oil transport equals to the quantity of crude oil exploitation. Vehicles such as pipelines, trains, and vessels are employed for crude oil transport, and it is consisted of pipeline transport, railway transport, road transport and vessel transport according to different modes of transport. With the increasingly frequent economic exchanges among countries, vessel transport becomes the primary mode of petroleum transport.

As the most environmental friendly transport mode, pipeline transport generates the minimum carbon dioxide. The pollution source mainly comes from the exhausts of combustion turbines. Pipeline transport is not commonly used in China, and the quantity of generated carbon dioxide is relatively smaller, hence the carbon dioxide emission of pipeline transport is not discussed in this paper.

Road and railway transports are important modes of petroleum transport. Exhaust fumes are the dominant emission source of such modes. The quantity of carbon dioxide emission during road and railway transports is not only related to the types of equipment being used, but also closed associated with the types of transport equipment, driving conditions and environment. Guo Yingjie of Dalian University of Technology has conducted relevant studies, and his study results are directly referred as the coefficients to calculate the quantity of carbon dioxide emission generated during road and railway transports, as shown in Table 5:

Table 5 - CO_2 Emission Coefficient Table of Different Transport Modes

Transport mode	Carbon dioxide emission coefficient
Railway (Diesel Locomotive)	0.23kg CO_2 / (t*km)
Road (Gasoline)	0.12kg CO_2 / (t*km)
Road (Diesel)	0.16kg CO_2 / (t*km)

Vessel transport is the primary mode of petroleum transport during which the combustion of diesel engine is the main source of carbon dioxide, of which the emission coefficient is shown in Table 6:

Table 6 - CO_2 Emission Coefficient Table in the Process of Shipping

Transport mode	Carbon dioxide emission coefficient
Ship	0.6414kg CO_2 / (t*km)

Table 7 - Average Transport Mileage of Freight Sharing Rate of Various Transport Modes

	Average transport mileage	Sharing rate
Tanker	11000 km	0.5
Railway	950 km	1.45
Pipeline	500 km	0.05

Source: China Statistical Yearbook

The carbon dioxide emission verification model during petroleum transport:

$$C_2=Q_{Oc}\,(a_1*P_1*A_1+a_2*P_2*A_2+a_3*P_3*A_3+ a_4*P_4*B_1) \quad (4\text{-}4)$$

C_2 is the carbon dioxide emission quantity generated during petroleum transport (*kg*); Q_{Oc} is the quantity of petroleum exploitation (*t*); P_1 is the carbon emission coefficient of railway (diesel locomotive) ($kg\ CO_2/(t*km)$); A_1 is the mileage of the locomotive (*km*); P_2 is the carbon emission coefficient of gasoline-driven petroleum transport vehicles ($kg\ CO_2/(t*km)$); A_2 is the mileage of gasoline-driven petroleum transport vehicles (*km*); P_3 is the carbon emission coefficient of diesel-driven petroleum transport vehicles ($kg\ CO_2/(t*km)$); A_3 is the mileage of diesel-driven petroleum transport vehicles (*km*); P_4 is the carbon emission coefficient of vessel transport ($kg\ CO_2/(t*km)$); B_1 is the mileage of vessels (*km*); and a_i is the proportions of each transport mode, % ($i=1, 2, 3, 4$).

(4) Petroleum refining

After exploitation and transport, petroleum is sent to oil refinery for refining. Refining divides crude oil into different types of products, and it includes three parts which are primary processing, secondary processing, and third processing. In primary processing, crude oil is distilled, and it is divided into different boiling ranges, also known as distillation cut; in secondary processing, the distillation cut obtained in primary processing goes through catalysis, hydrogen cracking, delayed coking, catalytic reforming and hydro-refining and it is converted into tank oil; in third processing, the tank oil obtained in secondary processing goes through cracking where organic chemical raw materials are obtained.

Waste gases generated from petroleum refining include fuel-burned fumes and production waste gas. Fuel-burned fume normally belongs to elevated continuous and stable emissions, and the major pollutants included are sulfur dioxide, oxides of nitrogen, carbon monoxide and smoke dust etc.; production waste gas refers to pollutants generated from the production process including catalytic cracking regenerated fume, Claus sulfur recovery exhaust, oxidized asphalt exhaust and effluent gases resulted from oil volatilization etc.; the carbon emission quantity resulted from petroleum refining is relatively smaller, hence not included in this paper.

(5) Diesel transport

The diesel produced after petroleum refining shall be transported to wharfs. Modes of transport differ since the traffic conditions in different places are different, hence different carbon dioxide emission. The carbon emission coefficients of different modes of transport are shown in the following table:

Table 8 - Various Discharge Coefficient of the Transport Modes

Transport mode	Carbon dioxide emission coefficient
Railway (Diesel Locomotive)	0.23 CO_2 / (t*km)
Road (Gasoline)	0.12 CO_2 / (t*km)
Ship	0.6414 CO_2 / (t*km)
Road (Diesel)	0.16 CO_2 / (t*km)

Source: China Transport Statistical Yearbook

Table 9 - Average Transport Mileage of Freight Sharing Rate of Various Transport Modes

	Average transport mileage	Sharing rate
Waterway	8200km	0.4

Railway	900km	0.5
Road	50km	0.1

Source: China Transport Statistical Yearbook

The carbon dioxide emission verification model during diesel transport:

$$C_3=Q_{Oc}(a_1*P_1*A_1+a_2*P_2*A_2+a_3*P_3*A_3+ a_4*P_4*B_1) \tag{4-6}$$

C_3 is the carbon dioxide emission quantity generated during diesel transport (*kg*); Q_{Oc} is the quantity of diesel consumption per unit time period for RTG operation (*t*); P_1 is the carbon emission coefficient of railway (diesel locomotive) ($kg\ CO_2/(t*km)$); A_1 is the mileage of the locomotive (*km*); P_2 is the carbon emission coefficient of gasoline-driven petroleum transport vehicles ($kg\ CO_2/(t*km)$); A_2 is the mileage of gasoline-driven petroleum transport vehicles (*km*); P_3 is the carbon emission coefficient of diesel-driven petroleum transport vehicles ($kg\ CO_2/(t*km)$); A_3 is the mileage of diesel-driven petroleum transport vehicles (*km*); P_4 is the carbon emission coefficient of vessel transport ($kg\ CO_2/(t*km)$); B_1 is the mileage of vessels (*km*); and a_i is the proportions of each transport mode, % ($i=1, 2, 3, 4$).

3. Carbon emission calculation model of downstream stage

The carbon emission calculation model of upstream stage refers to the calculation of the carbon dioxide emission quantity generated by diesel-driven gantry cranes in the container terminal. The yard operation of gantry cranes in the container terminal includes four states which are loading, unloading, picking up container, and container-waiting, as in the RTG enters the operation state as long as it enters the yard. The built-in generator set of RTG serves as the main driving force for its operations, and it is driven by high-power diesel engines. The running of diesel engines relies on diesel combustion. The operations of RTG consume lots of fuels, and generate lots of carbon dioxide, imposing significant impact on the terminal. The carbon emission coefficient of diesel combustion is 3.06 kg CO_2/kg according to the calculation methods issued by Intergovernmental Panel on Climate Change (IPCC) in 2006 in combination of the calorific values of different primary energies provided by China Energy Statistical Yearbook.

The carbon emission verification model of diesel-driven RTG

$$C_4=a*B*P \tag{4-6}$$

C_4 is the carbon dioxide emission quantity generated by diesel-driven gantry crane in the container terminal per unit time period (*kg*); a is the diesel consumption per standard container; B is the quantity of standard containers being operated by gantry crane in the container terminal within a unit time period; P is the carbon dioxide coefficient of diesel, ($kg\ CO_2/t$).

4. The full life cycle carbon emission verification model of diesel-driven RTG

$$C_O=C_1+C_2+C_3+C_4 \tag{4-7}$$

Where, C is the full life cycle carbon dioxide emission of diesel-driven RTG (*kg*); C_1 is the carbon dioxide emission quantity during petroleum exploitation (*kg*); C_2 is the carbon dioxide emission quantity during petroleum transport (*kg*); C_3 is the carbon dioxide emission quantity during diesel transport (*kg*); C_4 is the carbon dioxide emission quantity generated by RTG per unit time period (*kg*).

4.4.2 Full Life Cycle Carbon Emission Calculation Model of Electricity-Driven Rubber-tyred Gantry Crane

1. Objective and range of full life cycle carbon emission of electricity-driven RTG

Coal is the main source of thermal power generation in China, and coal-fired power generation is the main form of power supply in China. Therefore, only coal-fired power generation is studied in our study on the full life cycle carbon emission calculation of electricity-driven RTG. The full life cycle assessment of electricity-driven RTG includes coal production, thermal coal transport, coal-fired power generation and the operation of RTG, among which coal production, thermal coal transport and coal-fired power generation constitute the upstream stage of the fuel's life cycle assessment; the operation of RTG constitutes the downstream of the fuel's life cycle assessment, among which substances, energy and capital are the inputs to the system, while greenhouse gas emission is the output from the system.

As shown in Figure 9:

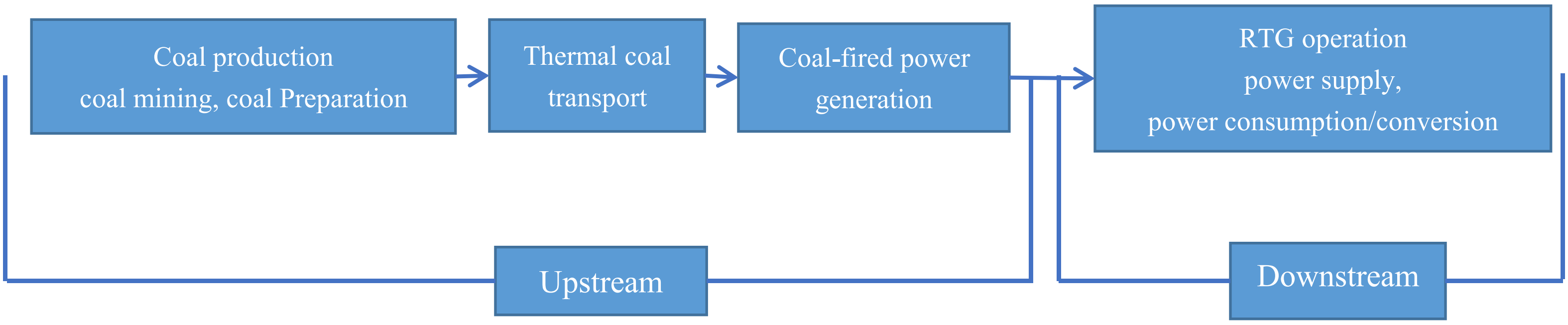

Figure 9 - Electricity-driven Gantry Crane Calculation Scope in Full Life Cycle

Source: Own presentation

2. The carbon emission calculation model of upstream stage

The upstream stage of the full life cycle carbon emission calculation of electricity-driven RTG can be further elaborated according to its specific chain of operations and procedures, as shown in the figure:

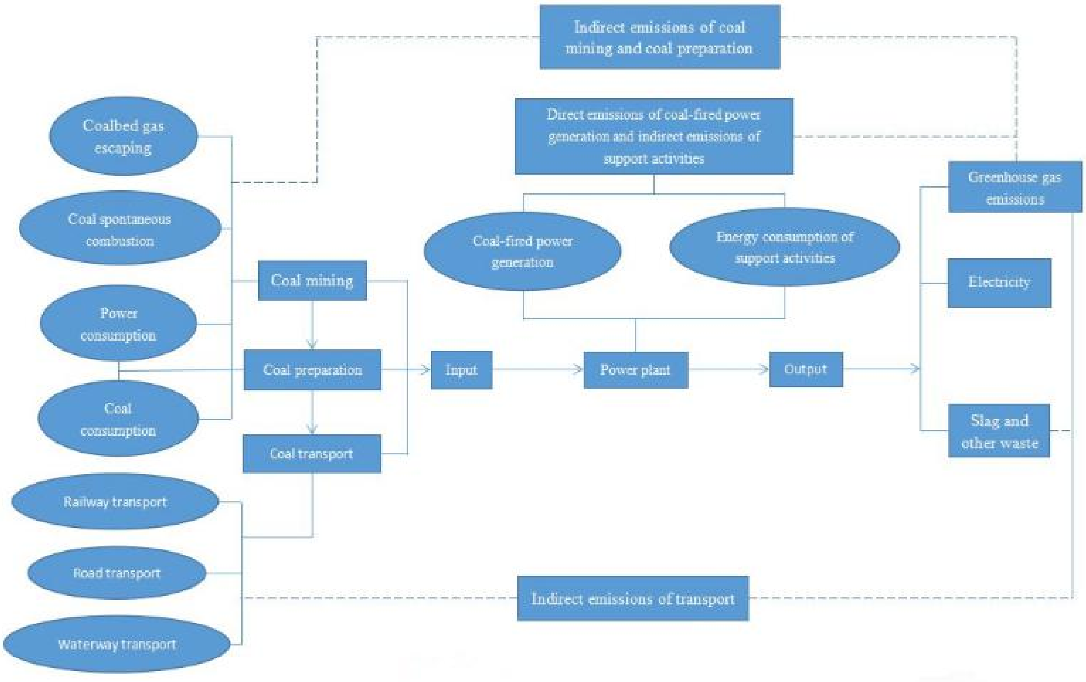

Figure 10 - Carbon Emissions Measurement Range of Electricity-Driven Gantry Crane Upstream Phase

Source: Own presentation

(1) To calculate the carbon dioxide emission generated in the upstream stage of electricity-driven RTG, the required raw coal production of electricity consumption per unit time period for RTG operation shall be confirmed, as required by principle of coal-electricity chain. The calculation equation is as follows:

$$Q_e = a*B \tag{4-8}$$

$$Q_c = Cs_g*d_{cs}*Q_e \tag{4-9}$$

Where Q_e is the required raw coal production quantity *t*; Cs_g is the standard coal consumption of a power plant (*g/kwh*): 342 g/kwh (2014 Statistical Bulletin); d_{cs} is the mass-energy transfer coefficient of standard coal transferring into the mass of raw coal of the same quantity of heat: 0.7143 (2013 China Statistic Yearbook); Q_e is the electricity consumption of RTG per time period (k*wh*); a is the electricity consumption per standard container; *B* is the quantity of standard containers being operated by gantry cranes in container terminal per unit time period.

(2) Coal production

The carbon emission mainly takes place during coal exploitation and coal washing during the coal production process, and the emission sources are mainly energy consumption, coal bed gas leakage and spontaneous combustion of coal.

1) Coal exploitation

The electricity consumption of mining equipment and the fuel consumption of mining equipment during coal production are the main sources of carbon emission. The energy consumption per ton of coal being exploited is estimated in this paper according to the energy consumption indicators per ton of coal being exploited in China in 2010 and 2015 provided by China Coal Science Academy, as shown in Table 10:

Table 10 - Coal Mining Tons of Coal for Energy Consumption Indicators in China

Year	National average	
	Electricity/kwh	Coal/kg
2010	33	27.7
2015	34.4	26.7
Estimation	34	27

Source: China Coal Science Academy

The calculation model of the quantity of carbon emission at coal mining stage:

$$C_1 = Q_c(\sum_{x \in X} U_p^x U_{ep}^x) \tag{4-10}$$

Where, C_1 is the carbon dioxide emission (g) during coal exploitation; Q_c is the exploited quantity of raw coal (t); U_p^x is the unit energy consumption generated by coal (coal: t/t, electric energy: Kwh/t); U_{ep}^x is the carbon emission coefficient (as shown in previous table); *x* is the fuel or energy being used in the production process which is raw coal and electric energy here; and X is the combination of them two.

2) The calculation model of the quantity of carbon emission resulted from coal bed gas leakage

Certain amount of carbon dioxide contained in coal bed gas is released during coal exploitation and washing. Approximately 11677.8g carbon dioxide is released for every ton of coal being exploited in China according to the statistics provided by the energy project team of National Development and Reform Commission of China.

The calculation model of the carbon emission quantity resulted from coal bed gas leakage:

$$C_2 = Q_c * Q_{ce} \tag{4-11}$$

Where, C_2 is the carbon dioxide quantity that leaked out of the coal bed gas (g); Q_c is the exploited quantity of raw coal (t); and Q_{ce} is the quantity of released carbon dioxide released per ton of coal (g/t).

3) The calculation model of carbon emission resulted from coal spontaneous combustion

The loss that takes place in coal exploitation mainly comes from the loss of coal spontaneous combustion. Approximately 0.01 t of raw coal is lost due to spontaneous combustion for every ton of raw coal being exploited.

The calculation model of the carbon emission resulted from coal spontaneous combustion:

$$C_3 = U_p * Q_c * Q_{ce} \tag{4-12}$$

Where, C_3 is the carbon dioxide emission resulted from coal spontaneous combustion (g); U_p is the carbon dioxide emission coefficient of raw coal (as shown in previous table); Q_c is the exploited quantity of raw coal (t); and Q_{ce} is the loss resulted from coal spontaneous combustion (0.01t/t).

4) The calculation model of the quantity of carbon emission resulted from the energy consumption of coal washing

The washing equipment consumes electric energy and generates greenhouse gases during coal washing. According to China Coal Science Academy, the electric energy consumption for the washing of each ton of coal is approximately 3 kwh.

The calculation model of the carbon emission resulted from the energy consumption of coal washing:

$$C_4 = U_p * Q_c * Q_{ce} \tag{4-13}$$

Where, C_4 is the carbon dioxide emission resulted from coal washing energy consumption (g). U_p is the carbon dioxide emission coefficient (as shown in previous table) of electricity; Q_c is the exploited quantity of raw coal (t); and Q_{ce} is the electric energy consumption per ton of coal (3Kwh/t).

5) The quantity of carbon dioxide emission resulted from coal exploitation

$$C_p = C_1+C_2+C_3+C_4 \tag{4-14}$$

Where, C_p is the carbon dioxide emission quantity resulted from coal exploitation (g); C_1 is the carbon dioxide emission quantity resulted from coal exploitation (g); C_2 is the carbon dioxide emission quantity resulted from coal washing energy consumption (g); C_3 is the carbon dioxide emission resulted from coal spontaneous combustion (g); C_4 is the carbon dioxide emission resulted from coal washing energy consumption (g).

(3) Thermal coal transport

The carbon emission during transport is mainly attributed to the exhausts of coal-transporting vehicles. Major modes of coal transport include railway, road and waterway, among which railway has always been the principal mode in coal transport industry. The tables regarding “freight transport turnover” statistical yearbooks of different years show that railway has always been occupying about 50% of all coal transport since 1990s. Therefore, the share rate of railway transport in this paper takes 50%; while no reliable statistics about the share rates of road and waterway transport were found, and they are assumed as 30% for road transport and

20% for waterway transport in this paper according to relevant statistics provided by China Coal Science Academy and transport sections.

The fuel used in railway transport of coal in the coal transport system of China is mainly diesel; while medium and heavy duty trucks of 20 t and above in road transport often use diesel as well; the fuel used in waterway transport is mainly fuel oil (i.e. residual oil). The types of oil used in waterway transport received approximate treatment in this paper due to the missing of statistics. Vessels that transport coal are assumed to be using diesel in this paper since the main engine of steamers mainly use residual oil or heavy diesel, while the auxiliary engine of steamers, fire pumps and lifeboats use diesel.

Losses arising from littering and flying dust are frequent during the loading and transport of coal. The estimation of China Coal Science Academy shows that such losses occupy approximately 0.5%-1%, which is fairly small, therefore the littering rate of coal is assumed as 0 in this paper, namely the volume of coal transport equals the quantity of coal exploitation.

Diesel locomotives and electric Locomotives basically undertake all passengers and cargo transport in railway transport, of which the average haul distance is 595 km (2011, State Statistics Bureau). The statistics of railway transport show that the data in 2010 is relatively complete, so the data of this year is employed as the reference in this paper.

Table 11 - Diesel Locomotive and Electric Locomotive in 2010 as A Proportion of the Railway Transportation

Diesel locomotive	57.3%
Electric locomotive	42.7%

Source: Ministry of railways

Table 12 - The Strength of the Diesel Locomotive and Electric Locomotive Fuel Consumption in 2010 (China Traffic Statistics Yearbook 2011)

Diesel locomotive (kg/(10kt.km)	24.6
Electric locomotive (kwh/(10kt.km)	111.8

Source: China Traffic Statistics Yearbook

Currently, there is no investigations regarding the energy consumption data of waterway or road transport of coal carried out by authoritative organization, so the energy consumption intensity and average haul distance of them two are estimated accordingly as shown in Table 13 based on the extensive analysis of industry reports regarding the average energy consumption levels of waterway or road transport.

Table 13 - The Energy Intensity and the Average Haul Distance of Road or Waterway Transport

	Road	Waterway
Energy consumption intensity	600kg/(10kt.km)	60kg/(10kt.km)
Average length of haul	65km	2261km

Source: Industry reports

The calculation model of the carbon emission resulted from thermal coal transportation:

$$C_s = \sum_{i \in I} \sum_{j \in J} U_i^j U_{pi}^j r_i^j Q_i^j M_i \qquad (4\text{-}15)$$

$$Q_c = \sum_{i \in I} \sum_{j \in J} r_i^j Q_i^j \qquad (4\text{-}16)$$

Where, C_s is the carbon dioxide emission quantity resulted from thermal coal transport (g); Q_c is the quantity of coal being transported (t); U_i^j is the energy consumption intensity of vehicle *i* that uses *j* fuel or energy (t/(t*km)); U_{pi}^{j} is the carbon emission coefficient of vehicle *i* that uses *j* fuel or energy (g CO_2/t, g CO_2/kwh); r_i^j is the share rate of vehicle *i* that uses *j* fuel or energy %; Q_i^j is the total quantity of coal being transported by vehicle *i* that uses *j* fuel or energy (t); and M_i is the average haul distance of vehicle *i* (km).

(4) Coal-fired power generation

$$C_g = Q_e U_g * U_{eg} \tag{4-17}$$

Where, C_g is the carbon dioxide emission quantity resulted from the power generation g; Q_e is the electricity consumption per unit time period for the operation of RTG, kwh; U_g is the standard power supply coal consumption per quantity of electricity, 342 g/kwh (2014, Statistical bulletin); U_{eg} is the carbon emission coefficient of per ton of standard coal consumed, 2.4567 g CO_2 /tce (recommended by the energy project team of National Development and Reform Commission of China).

(5) The calculation model of the carbon emission quantity during the upstream stage:

$$C_a = C_p + C_s + C_g \tag{4-18}$$

Among which, C_a is the carbon dioxide emission quantity during the upstream stage g; C_p is the carbon dioxide emission quantity resulted from coal production g;

C_s is the carbon dioxide emission quantity resulted from thermal coal transport g; C_g is the carbon dioxide emission quantity resulted from coal-fired power generation, g.

3. The calculation model of the carbon emission quantity during the downstream stage

The calculation model of the carbon emission quantity during the downstream stage is in fact the carbon dioxide emission quantity per unit time period when the electricity-driven RTG in container terminal is working. The carbon dioxide emission coefficient of electricity consumption is obtained according to the calculation methods issued by Intergovernmental Panel on Climate Change (IPCC) in 2006 in combination of the calorific values of different primary energies provided by China Energy Statistical Yearbook, which is 0.43 kg CO_2/kwh.

$$C_b = a * B * P \tag{4-19}$$

C_b is the carbon dioxide emission quantity of the electricity-driven RTG in container terminal g; a is the electricity consumption per standard container kwh; B is the quantity of standard containers being operated by the RTG in container terminal per unit time period; P is the carbon dioxide emission coefficient of electricity g, CO_2/kwh.

4. The calculation model of the full life cycle carbon emission quantity of electricity-driven RTG

$$C_e = C_a + C_b \tag{4-20}$$

Where C_e is the carbon dioxide emission quantity of electricity-driven RTG; C_a is the carbon dioxide emission quantity of the upstream stage; C_b is the carbon dioxide emission stage of the downstream stage.

4.5 Carbon Emission Calculation of Rubber-tyred Gantry Crane “Fuel to Electricity” Based on Dalian Port

Dalian Port is used as the example in this paper for the comparison of the carbon dioxide emission generated by external energy of “fuel-electricity” RTG that operates containers. The “fuel-electricity” transformation of RTG has been activated in Dalian Port since 2011. For the convenience of further studies, the carbon dioxide emission quantity generated by the external energy of the RTGs in the container terminal of Dalian Port in 2011 is calculated in this dissertation.

4.5.1 Full Life Cycle Carbon Emission Calculation of Fuel-Driven Rubber-tyred Gantry Crane

1. The carbon dioxide emission during the upstream stage

(1) The required petroleum quantity of the fuel consumption per unit time period for the operation of RTG

Table 14 - Port of Loading and Unloading Machinery and Using Equipment Unit Energy Consumption Indicators

Loading and unloading machinery	Unit energy consumption indicators
Electric tyred container portal crane	2kwh/TEU
Diesel-driven tyred container portal crane	0.85kg/TEU

The unit energy consumption of typical port loading & unloading machinery is assumed as the unit energy consumption of the loading & unloading machinery installed in the container terminal of Dalian Port.

Table 15 - Rubber-tyred Gantry Crane Operation Efficiency

Rubber-tyred Gantry Crane	30TEU/h

Source: Statistics of Dalian Port container terminal

$$Q_{oc} = a * P = 25.5 / h \tag{4-21}$$

$$Q_{os} = \frac{Q_{oc}}{T_{oc}} = 28kg / h \tag{4-22}$$

(2) The carbon dioxide emission resulted from petroleum exploitation

$$C_1 = Q_{oc}(P_1 * A_1 + P_2 * A_2) = 2.98kg \tag{4-23}$$

(3) The carbon dioxide emission resulted from petroleum transport

50% of the petroleum used in China is imported, so therefore the petroleum used is assumed as imported in this paper, from three major routes: the Persian Gulf – Strait of Malacca – Taiwan Strait – Dalian Port; North Africa – Mediterranean – Strait of Gibraltar – Cape of Good Hope – Strait of Malacca – Taiwan Strait – Dalian Port; West Africa – Cape of Good Hope – Strait of Malacca – Taiwan Strait – Dalian Port. The average mileage of these routes is 11000 km, most of which is waterway, as shown in Figure 11:

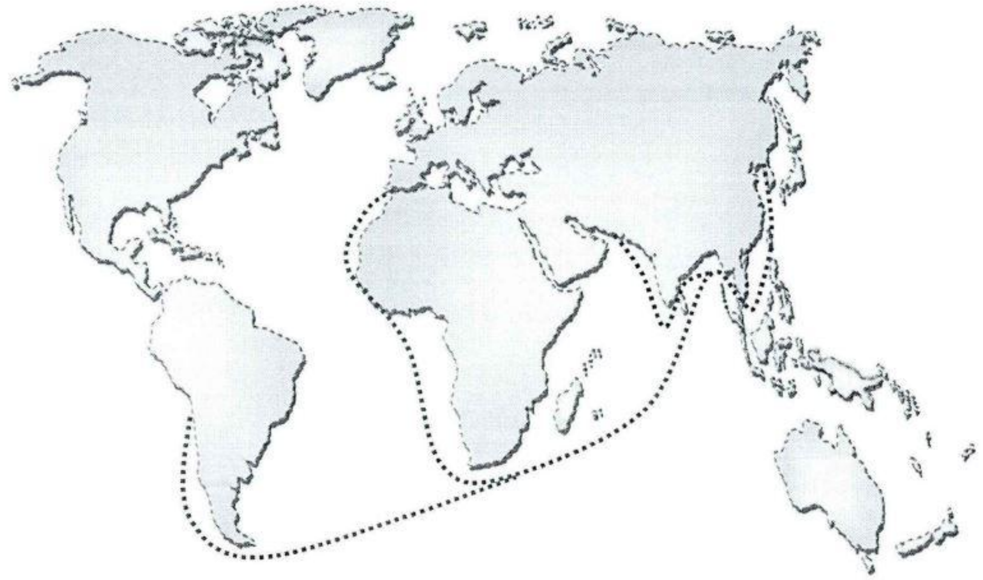

Figure 11 - The Main Route of Foreign Oil Import

$$C_2 = Q_{oc}(a_1 * P_1 * A_1 + a_2 * P_2 * A_2 + a_3 * P_3 * A_3 + a_4 * P_4 * B_1) = 197.55kg \quad (4\text{-}24)$$

The distance between Dalian Port and Dalian Petrochemical Co. is short, so the carbon dioxide emission quantity resulted from this distance can be ignored.

(4) The carbon dioxide emission resulted from fuel transport

Petroleum is refined in Dalian Petrochemical Co. for diesel production, which is then transported to Dalian Port on road, and the road distance is 16.4 km.

$$C_3 = Q_{oc}(a_1 * P_1 * A_1 + a_2 * P_2 * A_2 + a_3 * P_3 * A_3 + a_4 * P_4 * B_1) = 0.00656kg \quad (4\text{-}25)$$

(5) The carbon dioxide emission during the upstream stage

$$C_{os} = C_1 + C_2 + C_3 = 200.54kg \quad (4\text{-}26)$$

2. The carbon dioxide emission during the downstream stage

$$C_4 = a * B * P = 78.3kg \tag{4-27}$$

3. Full life cycle carbon dioxide emission of fuel-driven rubber-tyred gantry crane

$$C_o = C_{os} + C_4 = 278.54kg \tag{4-28}$$

Therefore, the fuel-driven rubber-tyred gantry crane produces 278.54kg carbon dioxide emission per hour from external energy.

4.5.2 Full Life Cycle Carbon Emission Calculation of Electricity-Driven Rubber-tyred Gantry Crane

This dissertation assumes that the power of the electricity-driven rubber-tyred gantry crane is supplied by Huaneng Power Plant in Dalian.

1. The carbon emission of upstream stage

(1) The required raw coal production of electricity consumption per hour for RTG operation

1) Electricity consumption per hour for RTG operation

$$Q_e = a * B = 60kwh / h \tag{4-29}$$

2) The required raw coal production of electricity consumption per unit time eriod for RTG operation

$$Q_c = C_{Sg} * d_{Cs} * Q_e = 14.66kg/h \tag{4-30}$$

(2) The carbon emission of coal production

1) The carbon emission of coal mining

$$C_1 = Q_c\left(\sum_{x \in X} U_p^x U_{ep}^x\right)$$

C_1=0.975kg (4-31)

2) The carbon emission of coal bed gas leakage

$$C_2 = Q_c * Q_{Ce} \tag{4-32}$$

C_2=0.1712kg

3) The carbon emission of spontaneous combustion of medium

$$C_3 = U_p * Q_c * Q_{Ce} \tag{4-33}$$

C_3=0.2903kg

4) The carbon emission of coal washing

$$C_4 = U_p * Q_c * Q_{Ce} \tag{4-34}$$

C_4=0.0189kg

5) The carbon emission resulted from coal exploitation

C_p = C_1+C_2+C_3+C_4=1.4554kg (4-35)

(3) The carbon emission of thermal coal transport

Dalian Huaneng Power Plant adopts thermal power generation, and the coals being used are transported from Shanxi railway station to Dalian railway station before they are transported to Dalian Huaneng Power Plant. The transport mode between Shanxi and Dalian is mainly railway, with the transport distance being 1428.8 km, and container trucks are used for the coal transport from Dalian railway station to Dalian Huaneng Power Plant, with the transport distance being 25.6 km.

$$C_s = \sum_{i \in I} \sum_{j \in J} U_i^j U_{Pi}^j r_i^j Q_i^j M_i = 0.1295kg \tag{4-36}$$

$$C_s = \sum_{i \in I} \sum_{j \in J} U_i^j U_{Pi}^j r_i^j Q_i^j M_i = 0.0225kg \tag{4-37}$$

(4) The carbon emission of coal-fired power generation

$$C_g = Q_e U_g * U_{eg} = 50.411kg \tag{4-38}$$

(5) The carbon emission of upstream stage

$$C_a = C_p + C_s + C_g = 52.0184kg \tag{4-39}$$

3. The carbon emission of downstream stage

$$C_b = a * B * P = 25.8kg \tag{4-40}$$

4. Full life cycle carbon emission of electricity-driven rubber-tyred gantry crane

$$\mathrm{C_e = Ca + C_b = 77.8184kg} \tag{4-41}$$

4.6 Comparative analysis

Table 16 - Dalian Port Container Terminal Rubber-tyred Gantry Crane Running External Energy Per Unit Time

Traditional RTG	278.54kg/h
Electricity-driven RTG	77.8184kg/h

The comparison between the carbon dioxide emission quantities of diesel-driven RTG and electricity-driven RTG in the container terminal of Dalian Port shows that the external energy of RTG imposes significant influence on its carbon dioxide emission quantity. The carbon dioxide emission quantity of diesel-driven RTG produces three times as much carbon dioxide as the electricity-driven RTG does. The “oil-electricity” process of RTG has obvious impact on ambient environment. Therefore the government shall enhance the financial support and encourage enterprises to convert RTGs as soon as possible to reduce the negative impact of their fumes on environment, realizing the sustainable development of Dalian Port.

Chapter 5 Benefit Analysis of Gantry Cranes "Fuel-to-Electricity"

Benefit analysis includes two aspects of economic benefit analysis and social benefit analysis. Economic benefit analysis is for enterprises, i.e., how enterprises achieve the maximum benefits at the minimum cost; social benefit analysis is for government, i.e., what policies of fiscal subsidies shall the government take to achieve the maximum benefits for society.

The chapter has conducted profound analysis of the economic and social benefits of gantry cranes "fuel-to-electricity", and a benefit optimized model is created for gantry cranes "fuel-to-electricity". Besides, the policies of government fiscal subsidies are analyzed, offering certain references for the government to make correct fiscal subsidy policies.

5.1 Economic Benefits Analysis of Gantry Cranes "Fuel-to-Electricity"

With the "fuel-to-electricity" of RTG, its power source shifted from diesel to electricity, hence its energy consumption cost alters accordingly. Take the data of 2015 as example for comparative analysis of the energy consumption cost of RTG.

The price of an ERTG is 7.8 million RMB in 2015 (of which the minimum service life is 20 years). It costs 6.5 million RMB to buy a traditional RTG, and it costs 1.05 million RMB to convert a traditional RTG, while a set of cables costs 500,000 RMB (of which the minimum service life is 5 years). Meanwhile, the major overhaul cost for an electricity-driven RTG is 8.3 yuan/hour, while the overhaul cost for a diesel-driven RTG is 5 yuan/hour.

Table 17 - Energy Consumption Index of Rubber-tyred Gantry Crane Operation Per Unit Time

Loading and unloading machine	Energy consumption per unit of time
Electricity-driven RTG	60kwh/h
Diesel-driven RTG	20.4L/h

Table 18 - The Market Diesel Prices and Electricity Cost for Enterprises in 2015

Diesel price	7.29yuan/L
Electricity cost	0.904yuan/kwh

Source: International Highway Association, World road statistics, National electricity Communique

The cost to convert an RTG:

$$C_g = \frac{P_{g1}}{T_{g1}} + P_e * Q_e * h + F_e * h + \frac{P_{e2}}{T_{e2}} \tag{5-1}$$

Where, C_g is the average annual cost of a converted gantry crane (daily expenses); P_{g1} is the conversion cost of “fuel-to-electricity” and the price of a gantry crane; T_{g1} is the service life of the gantry crane; P_e is the unit price of electricity; Q_e is the electricity consumption per unit period of operation; h is the operational hours of a gantry crane per year; T_{e2} is the applicable life of cable drums; P_{e2} is the price of a cable drum; and F_e is the unit price of engine maintenance.

The cost of a traditional gantry crane:

$$C_c = \frac{P_{c1}}{T_{c1}} + P_c * Q_c * h + F_c * h \tag{5-2}$$

Where, C_c is the cost of a traditional gantry crane; P_{c1} is the price of a gantry crane; T_{c1} is the service life of a gantry crane; P_c is the unit price of diesel; Q_c is a diesel consumption per unit period; h is the operational hours of a gantry crane per year; F_c is the unit price of engine maintenance.

Assume that RTG runs for 2920 hours every year, the daily cost of electricity-driven RTG per year is 335116.8 yuan; while the daily cost of diesel-driven RTG per year is 436937.12 yuan.

Previous comparative analysis shows that electricity-driven RTG saves more than one fourth of cost than traditional gantry crane does. Gantry cranes "fuel-to-electricity" may enterprises to save more costs, ensuring larger benefits for enterprises.

5.2 Economic Benefit Optimization Model of Gantry Crane "Fuel to Electricity" Based on Dalian Port Container Terminal

To encourage the initiative of enterprises in the "fuel-to-electricity" process of gantry crane, the government collects carbon taxes on enterprises that discharge carbon as reverse incentive. To pay the minimum economic cost within a certain planning period, enterprises will inevitably plan the "fuel-to-electricity" process of gantry cranes, and confirm the optimal number of gantry cranes to be converted, ensuring maximum economic benefits.

A dynamic planning model of “fuel-to-electricity” of gantry cranes is proposed in this paper, that is, the dynamic planning of the number of gantry cranes to be converted, ensuring that the cost for “fuel-to-electricity” of gantry cranes is minimal yet for maximum economic benefits.

Model hypotheses:

1. The capital for “fuel-to-electricity” of gantry cranes is the own fund of container terminal;
2. Purchase of new equipment in the beginning of each year within the plan;
3. Payment of carbon taxes at the end of each year within the plan;
4. If well maintained, a gantry crane runs for many years, so the model assumes that the life cycle of whether new and old gantry cranes is 20 years;
5. A certain planned period.

Variables and constraints:

Among which, C_E is the cost of enterprise within the planning period (yuan); C_1 is container crane’s cost for the purchase of cable drums (yuan); C_2 is the cost for the conversion of a container crane (yuan); C_3 is the electricity consumption cost of an electricity-driven container crane; C_4 is the diesel consumption cost of a diesel-driven container crane; C_5 is the carbon dioxide emissions tax (yuan); C_6 is the daily capitation fee of an e-gantry crane and a traditional gantry crane; T is the rate of carbon emissions tax (yuan/kg); h is the operational hours of a gantry crane per year (hour); C_e is the emission of carbon dioxide of an e-gantry crane per unit working hour (kg/hour); C_o is the emission of carbon dioxide of a diesel-driven gantry crane per unit working hour (kg); P_{i1} is the cost to purchase a cable drum container crane in the i^{th} Year (yuan); N_{i1} is the number of cable drum container cranes purchased in the i^{th} Year (unit); P_{i2} is the cost for the conversion of a container crane in the i^{th} Year (yuan); N_{i2} is the number of container cranes converted in the i^{th} Year (unit); b_i is the electricity consumption of a single ERTG in the i^{th} Year (yuan); a_1 is the fuel consumption cost of a single RTG in the i^{th} Year (yuan); r_i is the ratio of equipment upgrade investment loan in the i^{th} Year (%); I is the conversion period; c_i is the unit daily capitation fee of single e-gantry crane (yuan); d_i is the unit capitation fee of single traditional gantry crane (yuan).

Constraint (5-4) indicates that the “fuel-to-electricity” process of gantry cranes is finished after I year(s); constraint (5-5) indicates that the number of containers being handled by container crane shall meet the throughput capacity requirement of the container terminal of the year Q_i^*; constraint (5-6) indicates that the total owned amount for gantry cranes “fuel-to-electricity” of the year shall not be higher than the total amount available for equipment upgrade OF^* in the previous total revenue of the terminal; constraints (5-7), (5-8), (5-9) are integer constraints;

Model:

$$\begin{aligned}\min C_E &= C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \\ &= \sum_{i\in I} P_{i1}N_{i1} + \sum_{i\in I} P_{i2}N_{i2} + \sum_{i\in I} b_i(N_{i1} + N_{i2}) + \sum_{i\in I} a_i(N^* - \sum_{i=1}^{i=i} N_{i2}) \\ &+ \sum_{i\in I} T * h * [C_e * (\sum_{i=1}^{i=i} N_{i1} + \sum_{i=0}^{i=(i-1)} N_{i2}) + C_o * (N^* - \sum_{i=1}^{i=i} N_{i2})]\end{aligned} \tag{5-3}$$

$$+\sum_{i\in I}[C_i(\sum_{i=1}^{i=i} N_{i1} + \sum_{i=1}^{i=(i-1)} N_{i2}) + d_i(N^* - \sum_{i=1}^{i=i} N_{i2})]$$

$$\sum_{i\in I} N_{i2} = N^* \tag{5-4}$$

$$Q_e \sum_{i\in I} N_{i1} + Q_e * (N^* - N_{i2}) \geq Q_i^* \tag{5-5}$$

$$0 \leq (P_{i1}N_{i1} + P_{i2}N_{i2}) \leq OF^* \tag{5-6}$$

$$N_{i1} = 0,1,2,3...... \tag{5-7}$$

$$N_{i2} = 0,1,2,3...... \tag{5-8}$$

$$i = 1,2,3,......I \tag{5-9}$$

In 2011, Dalian Port began the “fuel-to-electricity” process of gantry cranes, so the data of 2011 is used as the foundation of this research. The total number of gantry cranes is 50, and the conversion period of gantry cranes is 5 years.

Table 19 - 2011-2015 Gantry Crane Fuel to the Modification Cost of Electricity (million yuan)

2011	2012	2013	2014	2015
90	95	100	105	109

Table 20 - 2011-2015 The Price of Electricity-driven Gantry Crane (million yuan)

2011	2012	2013	2014	2015
699	709	725	762	780

Table 21 - Electricity Prices in 2011-2015 (yuan/kwh)

2011	2012	2013	2014	2015
0.5521	0.521	0.619	0.815	0.904

Source: National electricity communique

Table 22 - Diesel Prices in 2011-2015 (yuan/kg) International Highway Association

2011	2012	2013	2014	2015
6.67	6.91	7.1	7.2	7.29

Source: World road statistics

Table 23 - Dalian Port Container Terminal Throughput in 2011-2015 (million TEU)

2011	2012	2013	2014	2015
434	503	582	640	810

Source: Statistical yearbook of dalian

Table 24 - The Total Annual Revenue of the Dalian Port Container Terminal can be used for the Total Cost of Equipment Renewal (million yuan)

2011	2012	2013	2014	2015
7200	7925	9200	9930	11000

Source: Statistical yearbook of dalian

Table 25 - China's Optimal Carbon Tax Credits in 2011-2015 (yuan/ton)

2011	2012	2013	2014	2015
7.31	9.50	12.49	25.79	30.38

LINGO is employed to solve linear planning issues and its optimal solution is obtained as follows:

Table 26 - The Optimal Results

	2011	2012	2013	2014	2015
Electricity- driven RTG	8	8	10	9	8
Transformed RTG	9	10	12	15	4

Source: Own calculation

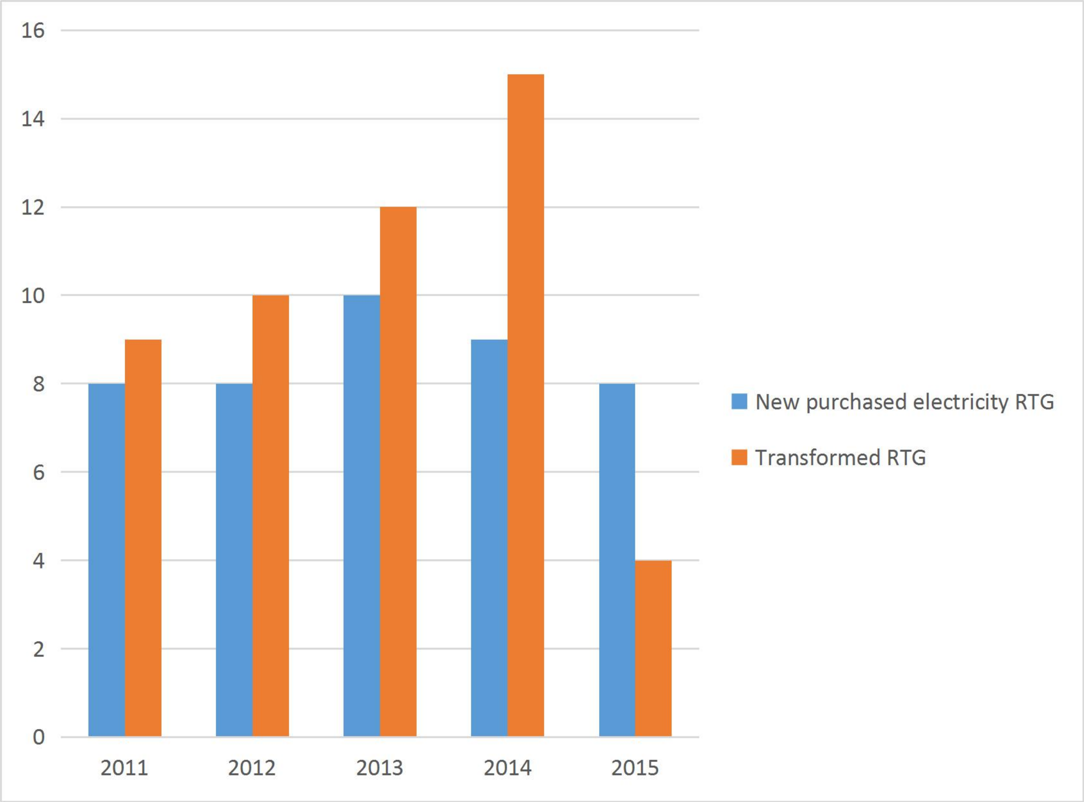

Figure 12 - The Optimal Results

Source: Own calculation

The table above shows that the enterprise may plan the numbers of purchased and converted gantry cranes per year in order to minimize the cost of the "fuel-to-electricity" process of gantry cranes while ensuring the normal operations of the terminal, thus maximizing its benefits. No monotone increase or decrease trend is shown in the numbers of purchased and converted gantry cranes.

5.3 Analysis of Government Fiscal Subsidy Policy Based on Dalian Port Container Terminal

1. To further facilitate "fuel-to-electricity" of gantry cranes, not only will the

government provide reverse incentives to the enterprises, but there will be positive incentives as well. For financial subsidies provided to the enterprise, different government subsidies may influence the initiative of the enterprises to conduct "fuel-to-electricity". This paper studies the difference in numbers of gantry cranes going through "fuel-to-electricity" caused by different government subsidies within the stipulated conversion period under the premise of the minimum total cost of the enterprises, in order to confirm which level of government subsidies is more suitable, so that government spending can be saved to the maximum extent, benefiting both the enterprises and the government.

Variables and constraints:

Among which, C_E is the cost of the enterprise within the planning period (yuan); C_1 is container crane's cost for the purchase of cable drums (yuan); C_2 is the cost for the conversion of a container crane (yuan); C_3 is the electricity consumption cost of an electricity-driven container crane; C_4 is the diesel consumption cost of a diesel-driven container crane; C_5 is the carbon dioxide emissions tax (yuan); C_6 is the daily capitation fee of an e-gantry crane and a traditional gantry crane; T is the rate of carbon emissions tax (yuan/kg); h is the operational hours of a gantry crane per year (hour); C_e is the emission of carbon dioxide of an e-gantry crane per unit working hour (kg/hour); C_o is the emission of carbon dioxide of a diesel-driven gantry crane per unit working hour (kg); P_{i1} is the cost to purchase a cable drum container crane in the i^{th} Year (yuan); N_{i1} is the number of cable drum container cranes purchased in the i^{th} Year (unit); P_{i2} is the cost for the conversion of a container crane in the i^{th} Year (yuan); N_{i2} is the number of container cranes converted in the ith Year (unit); b_i is the electricity consumption of a single ERTG in the i^{th} Year (yuan); a_i is the oil consumption cost of a single RTG in the i^{th} Year(yuan); r is the ratio of equipment upgrade investment loan in the i^{th} Year(%); I is the conversion period; c_i is the unit daily capitation fee of single e-gantry crane (yuan); d_i is the unit capitation fee of single traditional gantry crane (yuan).

Model:

$$\begin{aligned}\min C_E &= C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \\ &= \sum_{i\in I} P_{i1}N_{i1} + \sum_{i\in I} P_{i2}N_{i2} + \sum_{i\in I} b_i(N_{i1} + N_{i2}) + \sum_{i\in I} a_i(N^* - \sum_{i=1}^{i=i} N_{i2}) \\ &+ \sum_{i\in I} T * h * [C_e * (\sum_{i=1}^{i=i} N_{i1} + \sum_{i=0}^{i=(i-1)} N_{i2}) + C_o * (N^* - \sum_{i=1}^{i=i} N_{i2})] \\ &+ \sum_{i\in I} [C_i(\sum_{i=1}^{i=i} N_{i1} + \sum_{i=1}^{i=(i-1)} N_{i2}) + d_i(N^* - \sum_{i=1}^{i=i} N_{i2})]\end{aligned} \tag{5-10}$$

$$\sum_{i\in I} N_{i2} = N^* \tag{5-11}$$

$$Q_e \sum_{i\in I} N_{i1} + Q_e * (N^* - N_{i2}) \geq Q_i^* \tag{5-12}$$

$$0 \leq (P_{i1}N_{i1} + P_{i2}N_{i2}) \leq OF^* + C_g \tag{5-13}$$

$$N_{i1} = 0,1,2,3...... \tag{5-14}$$

$$N_{i2} = 0,1,2,3...... \tag{5-15}$$

$$i = 1,2,3,......I \tag{5-16}$$

Constraint (5-11) indicates that the “fuel-to-electricity” process of gantry cranes is finished after I year(s); constraint (5-12) indicates that the number of containers being handled by a container crane shall meet the throughput capacity requirement Q_i^* of the container terminal of the year; constraint (5-13) indicates that the total amount of “fuel-to-electricity” of gantry cranes of the year may not be higher than the total amount OF^* for equipment upgrade in the previous total revenue of the terminal and the amount C_g of government subsidies; constraints (5-14), (5-15), (5-16) are integer constraints.

2. Take Dalian Port as an example, different financial subsidies provided to the enterprise by the government may lead to different influences on the “fuel-to-electricity”.

This dissertation assumes that the enterprise is granted with different levels of government subsidies including 5 million yuan, 10 million yuan, 15 million yuan, 20 million yuan, 25 million yuan, and 30 million yuan. In addition, comparative analysis of different influences they may have imposed on the enterprise is carried out.

When the enterprise is granted with 5 million government subsidy, the numbers of purchased electricity gantry cranes and converted traditional gantry cranes are as follows:

Table 27 - The Optimal Results

	2011	2012	2013	2014	2015
New purchased electricity RTG	10	10	11	11	1
Transformed RTG	8	12	14	16	0

Source: Own calculation

When the enterprise is granted with 10 million government subsidy, the numbers of purchased electricity gantry cranes and converted traditional gantry cranes are as follows:

Table 28 - The Optimal Results

	2011	2012	2013	2014	2015

New purchased electricity RTG	10	10	12	11	0
Transformed RTG	10	12	15	13	0

Source: Own calculation

When the enterprise is granted with 15 million government subsidy, the numbers of purchased electricity gantry cranes and converted traditional gantry cranes are as follows:

Table 29 - The Optimal Results

	2011	2012	2013	2014	2015
New purchased electricity RTG	11	11	12	9	0
Transformed RTG	11	14	17	8	0

Source: Own calculation

When the enterprise is granted with 20 million government subsidy, the numbers of purchased electricity gantry cranes and converted traditional gantry cranes are as follows:

Table 30 - The Optimal Results

	2011	2012	2013	2014	2015
New purchased electricity RTG	11	12	13	7	0
Transformed RTG	11	14	17	8	0

Source: Own calculation

When the enterprise is granted with 25 million government subsidy, the numbers of purchased electricity gantry cranes and converted traditional gantry cranes are as follows:

Table 31 - The Optimal Results

	2011	2012	2013	2014	2015
New purchased electricity RTG	12	12	13	6	0
Transformed RTG	12	16	20	2	0

Source: Own calculation

When the enterprise is granted with 30 million government subsidy, the numbers of purchased electricity gantry cranes and converted traditional gantry cranes are as follows:

Table 32 - The Optimal Results

	2011	2012	2013	2014	2015
New purchased electricity RTG	13	13	14	3	0
Transformed RTG	12	17	20	1	0

Source: Own calculation

3. Comparative analysis

(1) The influences imposed on the “fuel-to-electricity” of gantry crane are illustrated as follows when the government increases from 5 million to 30 million:

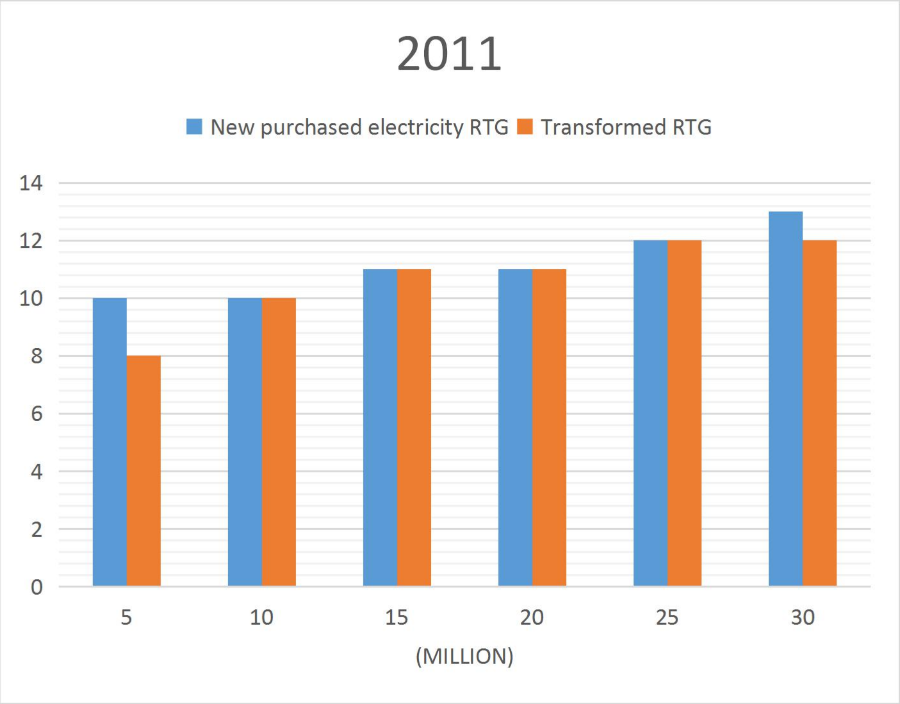

Figure 13 - The Optimal Results in 2011

Source: Own calculation

Figure 14 - The Optimal Results in 2012

Source: Own calculation

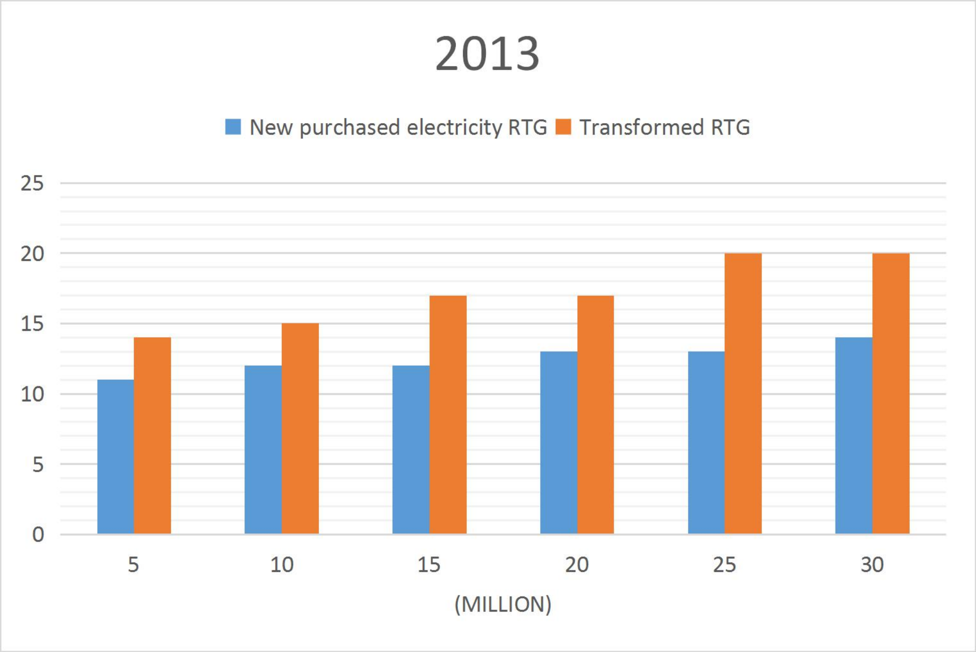

Figure 15 - The Optimal Results in 2013

Source: Own calculation

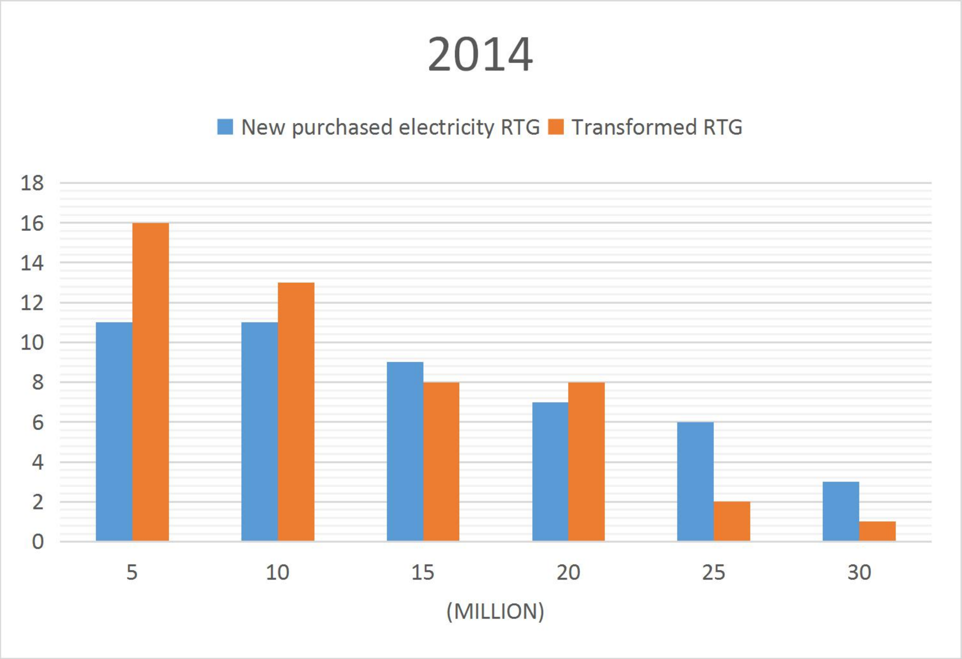

Figure 16 - The Optimal Results in 2014

Source: Own calculation

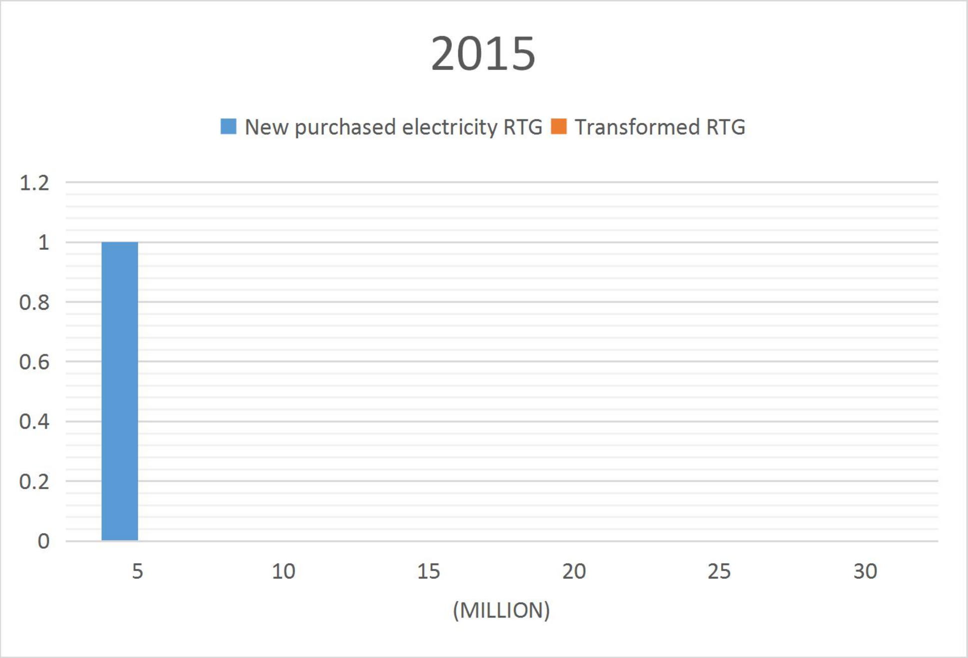

Figure 17 - The Optimal Results in 2015

Source: Own calculation

The graph above shows that as the government subsidies increase, the enthusiasm of the enterprise for conducting “fuel-to-electricity” becomes stronger. If financially possible, the enterprise is likely to conduct “oil-to-electricity” of gantry cranes. In this case, from 2011 to 2013, the number of e-gantry cranes used in terminals increased along with increasing government subsidies; from 2014-2015, the number of converted gantry cranes decreased along with the decreasing traditional gantry cranes. However, the number of e-gantry cranes purchased by the enterprise remained unchanged within a certain range regardless of government subsidies given the circumstance that normal production was maintained. Therefore, the actual situations of government shall be taken into consideration for appropriate government subsidies while offering positive incentives to the enterprise.

(2) The influences imposed on the carbon dioxide emissions in terminals are illustrated as follows when the government increases from 5 million to 30 million:

Table 33 - The Carbon Emissions under the Conditions of Different Government Subsidies during the Planning Period

Government subsidies	5million	10million	15million	20million	25million	30million
The carbon emissions during the planning period(t)	12810.77	12634.97	11990.39	11814.58	11404.40	11111.40

Source: Own calculation

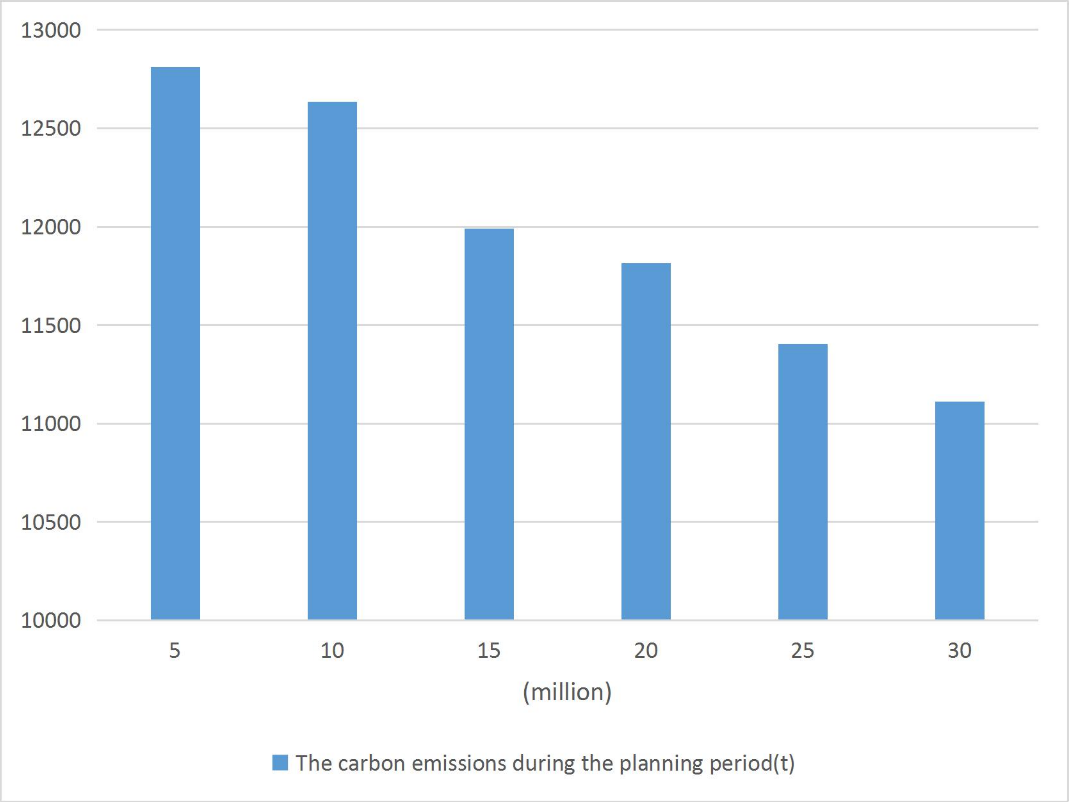

Figure 18 - The Carbon Emissions under the Conditions of Different Government Subsidies during the Planning Period

Source: Own calculation

The graph above shows that the government subsidies and the carbon dioxide emissions generated by gantry cranes are inversely related, i.e., the carbon dioxide emissions generated by gantry cranes decrease with the increase of government subsidies. Therefore, if financially possible, the government shall try its uttermost to provide appropriate capital subsidies to encourage the enthusiasm of the enterprise for conducting “fuel-to-electricity”, hence facilitating the completion of “fuel-to-electricity” of gantry cranes and making contributions to the environmental and sustainable development of terminals.

Chapter 6 Conclusion

Gantry cranes are one of the most important operating equipment in terminals. “Fuel-to-electricity” change of gantry cranes is of significance on the reduction of carbon dioxide emissions in terminals. From the perspective of full life cycle, the paper quantifies the reduction of carbon dioxide emissions caused by the external energy change of gantry cranes' “fuel-to-electricity”, more vividly elaborating the emission reduction effect. Moreover, the paper analyzes the optimal conversion strategies of the enterprise within a certain period while there is carbon emissions tax, ensuring that the enterprise makes contributions to society while lowering its own cost to the maximum extent. The policies of government subsidies are profoundly analyzed as well, and the results showed that the initiative of the enterprise to conduct “fuel-to-electricity” becomes higher along with increasing government subsidies. Therefore, the government shall provide financial subsidies to the enterprise as much as possible if financially allowed.

Following conclusions are obtained on the basis of summarizing previous studies:

(1) Gantry cranes “fuel-to-electricity” can reduce the carbon dioxide emissions in the terminal to a large extent. The carbon dioxide emissions of traditional gantry crane are 3 times higher than those of electricity-driven gantry crane. The

“fuel-to-electricity” is conducive to facilitating the sustainable development of terminals, hence making contributions to the realization of the objectives of China’s 12th Five-Year Plan.

(2) Under the condition that the government introduces “carbon emissions tax” to reversely stimulate gantry cranes “fuel-to-electricity”, enterprises can reduce their cost to the maximum extent through planning the number of gantry cranes to be converted within a certain planning period, thus achieving the maximum economic benefits to some extent.

(3) To stimulate the initiative of enterprises to conduct gantry cranes “fuel-to-electricity”, the government can also carry out positive incentive on enterprises through financial subsidies in addition to reverse incentive. Different government financial subsidies can generate different incentive effects on the “fuel-to-electricity” of enterprises. The higher the government subsidies, the higher the incentive for enterprises to carry out gantry cranes “fuel-to-electricity”, consequently better emissions reduction.

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