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Cap-and-trade or subsidy? governments' policy selection on emission reduction for maritime industry

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Cap-and-Trade or Subsidy? Governments' policy selection on emission reduction for maritime industry

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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.

Supervised by

Professor Zheng Shiyuan

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Thanks to everyone I met in WMU and SMU.

And best regards to my parents and relatives.

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List of Abbreviations

GHG **Greenhouse gas**

EU ETS **EU Emissions Trading Scheme**

AHP **Analytic hierarchy process**

Abstract

Cap-and-Trade or Subsidy? Governments' policy selection on emission reduction for maritime industry.

Degree: MSc

As the cleanest mode of transportation, water transportation is also facing severe pressure to reduce emissions, especially when IMO, organizations and countries are all trying to formulate goals or paths of international shipping "Decarbonization" , aiming to build a green shipping system. In this background, this paper compares the policies of Cap-and-Trade and Subsidy at the basis of theoretical analysis and model building.

The main work of this article includes 3 steps. Firstly, it qualitatively investigated the current situation of emission reduction in the maritime industry and then pointed out that the carbon dioxide emission source cannot be traced back and the lack of policy supervision leads to the delay of emission reduction in shipping industry due to the particularity of shipping industry.

Secondly, after defining the main problems and obstacles of carbon emission existed in maritime industry, this paper analyzes how these two policies guide enterprises to reduce emissions by stimulating enterprises.

With the goal of optimal emission reduction policy for shipping industry this paper established an Analytic Hierarchy Process model. Based on constructing the evaluation system, calculating the index weight and testing the data of this model, the results showed that Cap-and trade can make the optimal production quantity of production and operation activities reach the best proportion in the upstream and downstream cooperative emission reduction projects of the supply chain, and the subsidy mechanism can play a significant role in promoting the emission reduction effect of the shipping industry in the initial stage.

Based on the results of AHP model, this paper gives policy suggestions on cap-and-trade and subsidies respectively for governments. Besides, with the development of emission reduction policy, the derivative green finance industry will gradually mature and form a new green shipping system in the future.

Keywords: Cap-and-Trade; Subsidy; Carbon trading; EU - ETS; AHP

Chapter 1 Introduction

1.1 Background

In the background of global carbon emission reduction, more and more countries and major international organizations begin to pay attention to global warming. As the cleanest mode of transportation in the three major transportation systems, shipping industry is also facing severe pressure to reduce emissions. In particular, the carbon emission and environmental pollution of the port area have seriously affected the overall cleanliness of the shipping industry, which includes the carbon emissions of port operating equipment and carbon dioxide from fuel oil from ships in port. Therefore, it is one of the key issues for the major port and shipping enterprises to reduce the carbon emission of the operators in the port area.

At present, the most effective way for port side to reduce carbon emission is to improve the use level of handling equipment in the port and use electricity as a new energy instead of diesel oil. Besides, there are two methods for shipping companies to reduce carbon emission, the first is to control the ship's speed to reduce its own consumption, achieving the best fuel economy; the second is to use light and low sulfur oil to greatly reduce the pollutant emissions in the process of fuel oil.

However, all the above-mentioned approaches do not worked effectively due to the large investment in the early stage and the long cost recovery time. Therefore, the corresponding emission reduction policies came into being. At present, the most mainstream policy in the world called "Cap-and-Trade", which is carbon limits and carbon trading. For example, in the early stage of energy conservation and emission reduction, the national and local governments allocate corresponding carbon emission limits to different port areas, requiring enterprises to achieve the goal. Moreover, the port area exceeding the emission limit can purchase the corresponding emission quota from the market. Another emission reduction policy is not very popular among the countries called "Carbon Subsidy". The premise of the implementation of this policy is that the government and other official agencies set a carbon emission quote. Once it is exceeded, the relevant enterprises have to pay a certain number of fines to the government, which forcing high emission enterprises to reduce carbon emission.

1.2 Purpose

Generally speaking, “Cap-and-Trade” is widely used in shipping industry, while “Carbon Subsidy” is not very popular in the maritime industry. However, some European countries has achieved more effectively effect by using the policy of “Carbon Subsidy” than “Cap-and-Trade”. On the other hand, the development of “Cap-and-Trade” is utterly mature in the aviation industry, which has reference value in maritime industry. In this paper, we take reducing carbon emission in the maritime industry as a research goal, analyzing on the current situation of carbon emission of maritime industry. More importantly, we intend to deeply analyze the situation and obstacles of these two policies, comparing the advantages and disadvantages and providing suitable policy suggestions according to our countries’ own situation.

Based on China’s current policy environment and carbon trading market, this paper mainly force on four aspects as followed:

1. What is the current situation of emission reduction in maritime industry in recent years?
2. What is the main problems in low carbon development of China’s maritime industry?
3. How is the development of “Carbon Subsidy” and “Cap-and-Trade” in China?
4. Whether “Carbon Subsidy” or “Cap-and-Trade” is more suitable for China?

1.3 Literature review

The related literature can be categorized into three main streams: literature on the emission reduction in maritime industry; the establishment and development of carbon trading markets, and carbon tax collection and subsidy.

1.3.1 Emission reduction in maritime industry

The first stream of relevant literature is on the emission reduction in maritime industry. In the maritime carbon emissions trading system, it is difficult to establish an emission cap. Firstly, international shipping is developing rapidly. Secondly, there is great uncertainty in estimating the relevant carbon emissions (Beck, et al. 2013). On the other hand, there are plenty of researchers pay attention on the research of emission reduction in maritime industry. Dissou(2016) compares different carbon emission governance tools from different aspects: carbon tax and carbon trading, and concludes that the former has better social welfare effect, while the latter has better stability. Eto(2010) uses "Polluter Pays" (PPP) and "User pays" (UPP) tax calculation mode to study the carbon tax system and find out that the "User Pays" tax model has a more significant inhibitory effect on energy consumption. In terms of port side, the research results of Geerlings and van Duin(2011) show that the most effective measure to reduce carbon dioxide emissions is undoubtedly the adaptation of port layout, followed by the mixed use of bio-fuels and diesel. For shipping companies, Ching and Wang (2012) believes that the strategy of reducing ship speed is the most effective in reducing fuel consumption and cost as well as emissions. Yun et al. (2018) established data models to show that ship deceleration and LNG use can reduce carbon emissions.

Enterprises need to invest a lot of emission reduction funds. How should enterprises make decisions on emission reduction investment to achieve a win-win situation of environment and economy is very important. Subramanian et al. (2007) established a game model of enterprises in the carbon trading market under the auction mechanism. The research shows that the investment intensity of enterprise emission reduction is related to the nature of the industry and the initial quota. Klingelhfer (2009) used linear programming to study the impact of carbon trading mechanism on enterprise emission reduction technology investment.

1.3.2 Establishment and development of carbon trading

The second stream of relevant literature is on the establishment and development of carbon trading. In Europe, the aviation sector is the first to implement the EU ETS, lots of scholars have carried out a full study on it. For example, TOL (2007), based on the international passenger flow, uses the Hamburg tourism model (HTM) model to find that due to the difference of voyage and LTO stage, the impact of carbon emission cost on long routes is greater than that on short routes, especially when the levy scope is regional rather than global, the airlines in the levied region will lose part of the market share. Vespermann and Wald (2011) found that the carbon expenditure of aviation industry accounted for 1.25% of the total cost. Under EU-ETS, the industry paid an average of 3 billion euro more in carbon emission cost every year from 2012 to 2020. Girardet and spinler (2013) built a fuel surcharge model including kerosene and carbon dioxide emissions and simulated and analyzed the change of aviation demand and its impact on airline profitability according to the proportion of carbon emission cost transferred to consumers. Scheelhaase et al. (2010) calculated the fuel consumption and carbon emissions of airlines through the model construction, empirically analyzed the changes of operating costs, fares and freight rates of Lufthansa and Continental Airlines under EU ETS, and believed that continental airlines would operate relatively efficient long-distance transport services, while Lufthansa had relatively inefficient short-distance transport network. Meleo et al. (2015) takes Italy as an example to study the social cost of the aviation industry's inclusion in EU ETS. However, in terms of the maritime industry, Chang et al. (2013) used the catch model to study the relationship between the sailing speed of international transport ships and carbon emissions; Wang et al. (2015) analyzed and compared the different effects of closed internal carbon trading market and open inter industry carbon trading market on the fuel consumption and profitability of shipping enterprises; Segura S(2017) analyzes the impact of cap and trade on national and regional environment and economy from the perspective of government.Richard and William (2003) established a model including cost-benefit, time discount rate, stock survival time and uncertainty, and concluded that the net welfare brought by carbon tax is higher than that brought by carbon trading.For a global perspective, Murphy et al.(2017) believe that although global carbon trading is developing rapidly and the total amount of carbon trading is increasing, there is no unified carbon trading market in the world at present, and the problem of carbon leakage greatly reduces the emission reduction efficiency of carbon trading.Chang (2017) found that the scattered carbon trading market will produce market arbitrage opportunities, reduce the efficiency of resource allocation, and cause carbon leakage. Laffont and Tirole(1996) mainly consider the design of the market of carbon emissions. Hua (2011) et al.investigate the changes of carbon trace of the enterprise's inventory with carbon limitation in the carbon trade and construct the model of the optimal order quantity with the carbon constraint. Therefore, it is imperative to establish a national unified carbon trading market.

1.3.3 Carbon tax and subsidy

The third stream of relevant literature focus on carbon tax and subsidy. J. Corbett (2009) established a model with the goal of maximizing fleet profit, and gave the impact on speed, emission and cost under different fuel tax rates and carbon emission tax rates. H. Lindstad (2011) studies how to reduce the cost and greenhouse gas emissions by reducing the speed of ships. For the carbon tax policy, Pearce (1991) believes that a reasonable carbon tax policy can not only constrain enterprises to reduce carbon emissions, but also use to improve environmental quality and realize a low-carbon green economy. Some researchers summarized the current policies and guidelines of carbon emission in shipping industry and believed that the combination of carbon tax and technology can speed up the emission reduction in shipping industry. (Cullinane et al., 2013). Lee (2013) analyzed the impact of different marine carbon emission taxes on liner transportation and the world economy. When the carbon emission tax reaches 90 USD / ton, China's GDP will decrease by 0.02%. Mitra and Webster compare the cases when manufacturers or re-manufacturers alone get subsidy or when they both get subsidy.

With the introduction of policies such as carbon quotas and carbon taxes, many enterprises have also promoted low-carbon technological innovations that can adapt to the new competitive environment. Brauneis(2013) et al. found that stricter carbon emission policies can guide companies to adopt innovations in carbon emission reduction technologies. Luo (2014) et al. found that companies introduced capital investment in carbon emission reduction technological research and development into the supply chain game model based on the carbon trading mechanism. Deng (2019) et al. discussed the optimal strategies of governments and enterprises for fostering low-carbon technology innovations from the perspective of political competition.

To sum up, there are a lot of theoretical and policy research results on the effectiveness of carbon tax and carbon trading. They mainly focused on three aspects: Reduce carbon emissions from the operation of ports and shipping companies; learning from the European and American carbon tax system to guide the development of China's carbon tax system and focusing on improving carbon trading market to promote emission reduction of shipping industry. However, few literatures provide powerful guidance for government’s policy selection on emission reduction for the maritime industry and the comparison between these two policies. Besides, carbon trading market is still in an immature stage and carbon tax policy is not popular in maritime industry. Especially in China, we need a much more power policy means and macro control of market to promote the green development of the maritime industry. Different from the above literature, this paper focus much more on the perspective of the government and looking at the pros and cons of these two policies from the perspective of the government. The innovation of this paper lies in the integration this problem and provide a suitable suggestion for government's policy selection.

1.4 Dissertation structure

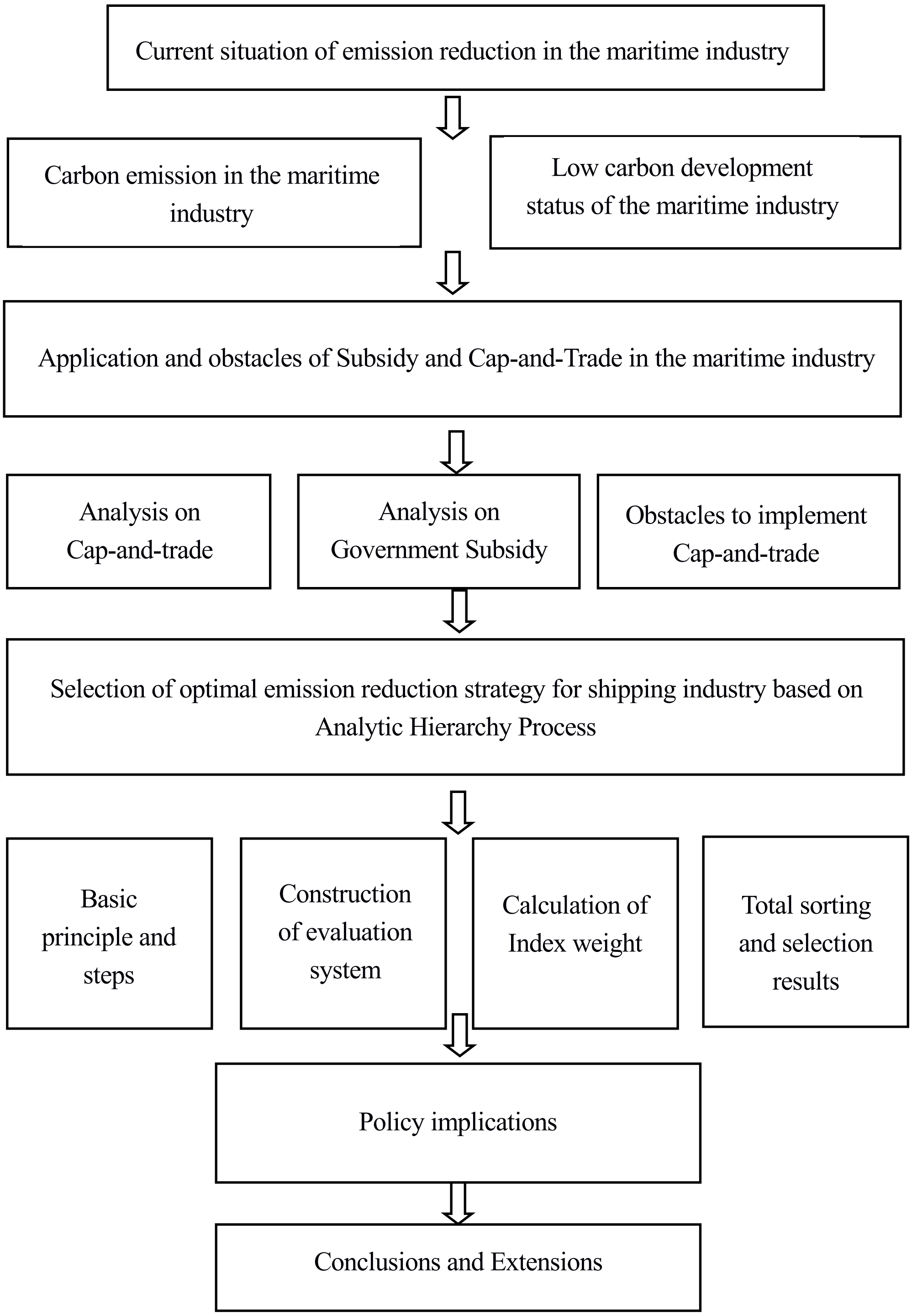

Figure 1 Dissertation structure

The rest of the thesis is organized as follows: Chapter 2 illustrates and analyze the current situation of emission reduction in the maritime industry. Chapter 3 introduces the Application and obstacles of "Subsidy" and "Cap-and-Trade" in the maritime industry. Chapter 4 tells author's own opinion and recommendation for the policy of 'cap-and-trade' and 'subsidy'. Chapter 5 make a conclusion and extensions for the whole paper.

Chapter 2 Current situation of emission reduction in the maritime industry

The rapid growth of global shipping carbon emissions has become a hot topic in the international community, especially for the concept of ‘Carbon-neutral’ and ‘Carbon-peak’ which recently pushed the issue of emission reduction to a climax again. At present, IMO has determined the technical and operational carbon emission reduction measures for ships in the form of legal texts, and the market emission reduction measures are still in the negotiation stage. In the process of international greenhouse gas negotiation, Kyoto Protocol puts forward three mechanisms of greenhouse gas emission reduction, namely ‘Clean Development Mechanism’, ‘Joint Implementation’ and ‘Emission Trading’. Besides, Article 2.2 of Kyoto Protocol mentions that IMO should make efforts to control greenhouse gas emissions from the maritime industry. Personally, I think emission reduction in maritime industry is a long-term and complex process, which needs huge efforts of various organizations including shipping companies, ports side, governments, and international organizations.

2.1 Carbon emission in maritime industry

2.11 Analysis on carbon emission status of maritime industry

Carbon emission is the abbreviation of greenhouse gas emissions. The main types of greenhouse gases leading to global warming are carbon dioxide, nitrogen dioxide, methane and so on, of which carbon dioxide is the main component. According to the data from Clarkson, the maritime industry has emitted about 810 million tons of carbon dioxide in 2020, accounting for 2.4% of the total global carbon dioxide emissions. More than 85% of the global freight transportation is completed by sea. Such a large carbon dioxide emission base can only be achieved through the marine industry’s own efforts. Although vital progress is still needed, shipping emissions have trended downwards since 2008(down ~20%, achieved mainly by a ~15% drop in speed, in part due to more fuel efficient designs) and shipping remains the most "carbon efficient" mode of transport (*3 rail and *9 truck).(Clarkson Research)

2.111 Comparative analysis among industries and transportation mode

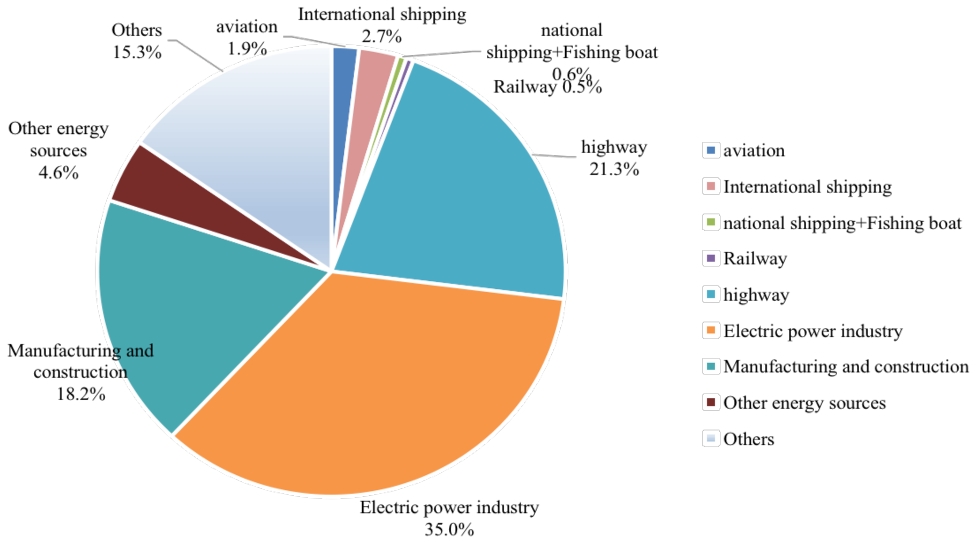

Figure 2 Carbon emission comparison between global maritime industry and other industries

Source: International Energy Agency, IEA

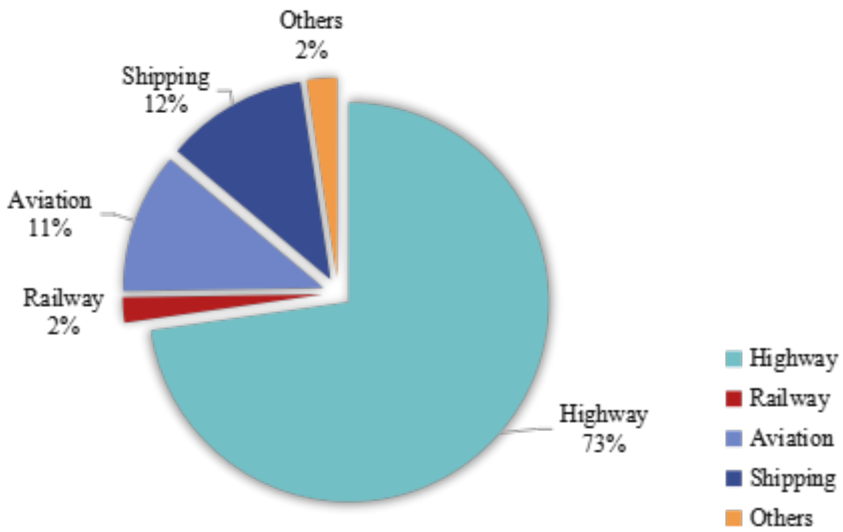

Figure 3 Comparison of carbon emissions between global shipping industry and other transportation industries

Source: International Energy Agency, IEA

In terms of greenhouse gas emission statistics, although the maritime industry undertakes most of the global trade and transportation, its total emission is still relatively low. Figure 2 shows carbon emission comparison between global maritime industry and other industries. We can find that the global carbon emissions mainly come from the power industry and manufacturing industry, accounting for 53.2% of the total emissions, the carbon emissions of transportation industry account for 27%, while only 3.3% for maritime industry. Figure 3 shows comparison of carbon emissions between global shipping industry and other transportation industries, which makes it clearer that as far as the carbon emission level of the global transportation industry is concerned, the carbon emission of the maritime industry is lower than that of the whole transportation industry.

From the data point of view, shipping has still remained “carbon efficient” mode of transport, while we can't ignore the huge amount of energy consumption and carbon emissions in maritime industry.

2.112 Analysis on carbon emission

Personally, it's important to combine "Tonne-miles" with "Carbon emission" when we analysis Overall emission situation of shipping industry. Figure 4 shows transport volume of world seaborne goods in recent twenty years. The volume of world seaborne trade and transportation distance have been growing steadily, from 31,049.5 billion Tonne-miles in 2000 to 58,902.5 billion Tonne-miles in 2020, an increase of over 80%. But at the same time, it is worth noting that the growth rate of carbon output of world shipping fleet is relatively slow, a increase about 10%, which seems like a gentle curve from Figure 5, and even the world shipping fleet carbon output as % of Global carbon output dropped sharply from 2008 to 2012, and then maintained a lower share of emissions from 2012 to 2020.

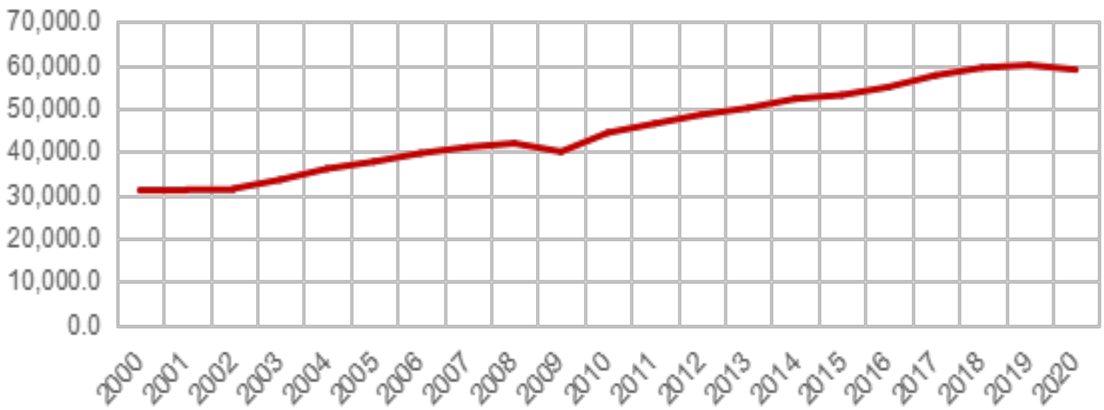

Figure 4 World Seaborne Trade Billion Tonne-miles

Source: Clarksons Research

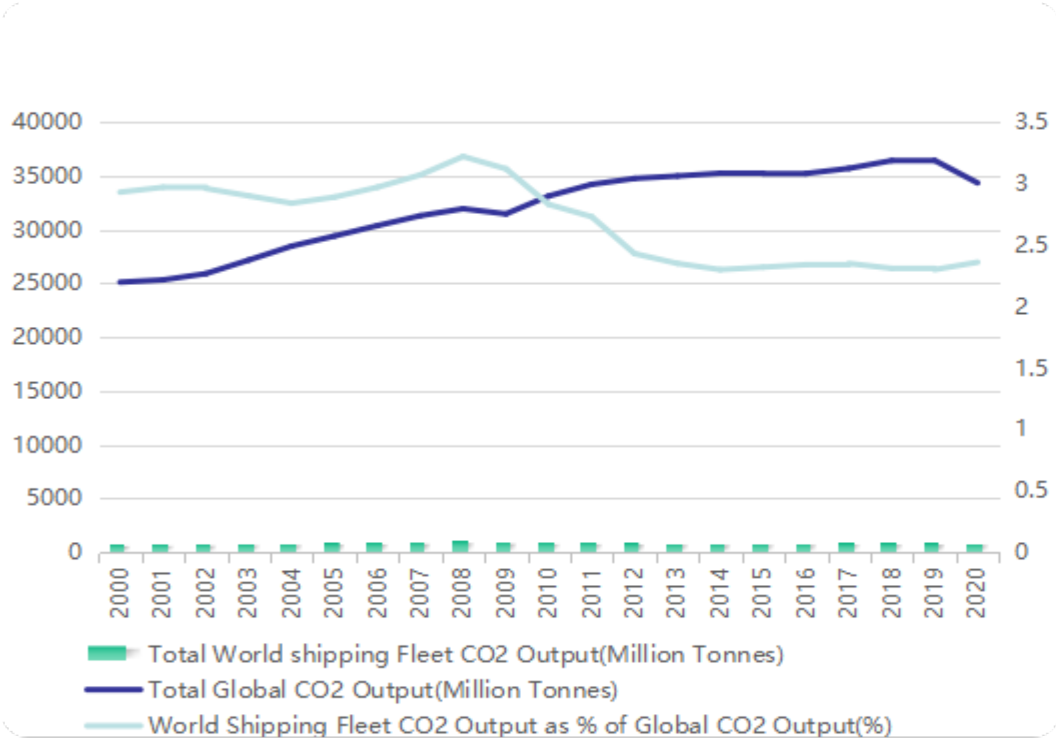

Figure 5 Total World Shipping Fleet CO2 Output Million Tonnes and others

Source: Clarksons Research

To further analyze the carbon output, we combine with these two kinds of data together showed in Table 1.

Table 1 Tonnes CO2/million tonne-miles

	World Seaborne Trade	Total World Shipping Fleet CO2 Output	CO2/tonne-miles
Date	Billion Tonne-miles	Million Tonnes	Tonnes
2000	31,049.5	734.41	23.7
2001	31,190.6	750.86	24.1
2002	31,405.0	767.48	24.4
2003	33,456.4	787.32	23.5
2004	36,009.1	809.17	22.5
2005	37,626.8	848.26	22.5
2006	39,591.6	900.55	22.7
2007	40,993.4	961.34	23.5
2008	41,876.6	1,027.52	24.5
2009	39,944.0	982.65	24.6

2010	44,326.9	935.73	21.1
2011	46,429.3	932.64	20.1
2012	48,516.3	845.92	17.4
2013	50,024.2	821.50	16.4
2014	52,162.5	810.86	15.5
2015	53,028.8	815.41	15.4
2016	54,890.0	823.68	15.0
2017	57,580.1	837.13	14.5
2018	59,346.7	841.51	14.2
2019	59,941.9	838.78	14.0
2020	58,902.5	810.42	13.8

Source: Clarksons Research

As can be seen from table 1, although the amount of world seaborne trade and total world shipping fleet CO2 output has increased over past 20 years, the carbon emission intensity of shipping has decreased from 23.7 tons per million tonne-miles to 13.8 tons per million tonne-miles. Meanwhile, the carbon emission intensity of shipping always keeps the state of decreasing gradually.

2.1.2. The characteristics of carbon emission in maritime industry

The carbon emission of maritime industry is mainly generated by two main bodies: port sides and shipping sides. The carbon emission of port side is mainly generated by the berthing ships and the operation of port equipment, while the carbon emission generated in the process of navigation due to the use of fuel is the main source of carbon emission of shipping sides. According to the two greenhouse gas reports of IMO in 2009 and 2014, the emission sources of shipping greenhouse gases and air pollutants are divided into four categories: 1. Exhaust emissions from ship fuel combustion. 2. The discharge of the cargo on board. 3. The discharge of refrigerant from the ship. 4. Other types of emissions. (IMO, 2009; 2014). In addition, the results of the second and third reports of IMO show that carbon emissions from the international shipping industry account for more than 80% of global shipping carbon emissions, far exceeding other types of shipping carbon emissions. Therefore, international shipping industry is the main contributor of global shipping carbon emission. (IMO, 2009; 2014)

According to the previous analysis, we can draw a conclusion that maritime industry is the cleanest mode of transportation, and the intensity of emission reduction is increasing by year. However, enterprises, governments and individuals are still facing severe pressure of emission reduction.

2.2. Low carbon development status of the maritime industry in China and the world

2.21 Low carbon development of the maritime industry in the world

1. <*United Nations Framework Convention on climate change*>

As far as I'm concerned, it's a cross-border problem to deal with the challenges of global climate change and reduce global greenhouse gas emissions, besides, it is hard to achieve it only by national power. Therefore, it is necessary to coordinate climate action at the global level. On May 9, 1992, the United Nations Intergovernmental Negotiating Committee reached a convention on climate change at the United Nations Conference on environment and development in Brazil, namely the 'United Nations Framework Convention on climate change'.

The <*UNFCCC*> entered into force on 21 March 1994. According to Article 2 of the <*UNFCCC*>, its main purpose is to coordinate global actions to mitigate climate change, and its goal is to "stabilize the concentration of greenhouse gases in the atmosphere at a dangerous level to prevent human interference in the climate system". Since then, this convention has become the first international convention with the main goal of limiting greenhouse gas emission. At the same time, the <*UNFCCC*> is also the basic framework of greenhouse gas emission reduction as well as international cooperation.

The Convention does not stipulate the specific obligations of the contracting parties or the specific implementation mechanism, which directly results in the lack of legal binding force of the Convention. In terms of shipping carbon emissions, the Convention has no specific obligations on transport emissions and shipping carbon emissions are not directly regulated by the Convention, but the parties to the Convention recognize the role of international climate strategies in controlling international shipping green gas emissions.

2. <Kyoto Protocol>

At the beginning of the signing of the <*UNFCCC*>, in order to attract all parties to sign the Convention as soon as possible, the committee didn't make specific provisions on specific emission reduction measures, targets and implementation methods for the sake of balancing interests but adopted the Convention in principle. In order to promote the implementation of the Convention, the committee adopted the protocol called "*Kyoto Protocol*" to the Convention on 11 December 1997. The Protocol came into force on February 16, 2005. It inherits the most important principle of common area in the Convention, so it also requires industrialized countries to take greater responsibility in solving environmental problems.

The <*Kyoto Protocol*> requires parties to set internationally binding emission reduction targets by 2020. Different from the vague objectives set by the Convention, the <*Kyoto Protocol*> sets quantitative targets for related countries. For example, according to Article 3 of <*Kyoto Protocol*>, the related countries should reduce the total emissions of six greenhouse gases by at least 5% from the 1990's level between 2008 and 2012. In addition, the Protocol has developed three flexible mechanisms for carbon emissions trading, including the emission trading mechanism.

However, the shipping sector is not covered by the <*Kyoto Protocol*>. Article 2.2 of the <*Kyoto Protocol*> states that "States parties included shall, through ICAO and IMO, respectively, strive to limit or reduce greenhouse gas emission of aviation and shipping cabin fuel not regulated by the "Montreal Protocol". In other words, Greenhouse gases emitted by shipping are not part of the national inventories under the <*Kyoto Protocol*>, so they are not bound by the agreed binding emission targets. Instead, the international maritime organization is responsible for the control of greenhouse gases emitted by international shipping.

3. Trends of IMO emission reduction

In accordance with Article 2.2 of the <*Kyoto Protocol*>, each Contracting Party shall seek legal assistance through the international maritime organization Control of greenhouse gas emissions from shipping. It means, the prevention and reduction of marine pollution caused by ships is one of the responsibilities of IMO.

IMO has adopted a series of measures and conventions to prevent and control ship pollution and the most important named <*MARPOL 73/78*>, which was adopted in 1973. Subsequently, aiming at the problem of air pollution caused by ships, the IMO conference deliberated and adopted a protocol to amend <*MARPOL 73/78*> in 1997, and added Annex VI to the original <*MARPOL 73/78*> convention, which made special provisions on air pollution caused by ships. In Annex VI of MARPOL 73 / 78, IMO has been entrusted with the responsibility of studying the greenhouse gas emissions from shipping and formulating scientific and feasible emission reduction strategies.

In November 2003, the general assembly of IMO Member States adopted a resolution on shipping emission reduction called <*IMO policy and Implementation on shipping greenhouse gas emission reduction*>. The resolution requires MEPC to determine the mechanism needed for shipping emission reduction and formulate a detailed work plan for shipping emission reduction. Besides, MEPC should give priority to the design of the calculation method of ship greenhouse gas efficiency according to the ship greenhouse gas emission index when it comes into mechanism design.

In the following ten years, most of their work on GHG emission reduction in shipping industry focused on the investigation of GHG emission status, such as emission statistics, proportion calculation, determination, and design of measurement methods. It was not until July 2011 that IMO really made substantial progress on the issue of greenhouse gas emission reduction from ships. More specifically, the "operation standard and ship emission reduction technology for greenhouse gas emission reduction of shipping ships" was formally included in *<MARPOL 73/78>* system, including the energy efficiency design index (EEDI) for newly designed ships and the energy efficiency management plan (SEEMP) for existing ships at the 62nd meeting of MEPC. Recently, IMO put forward the 2030 / 2050 target to reduce the carbon emission of shipping industry in 2018 and adopted the IMO short-term emission reduction measures at the 75th meeting of MEPC in November 2020, that is, introducing the existing ship energy efficiency index EEXI and carbon emission intensity index CII, to encourage all parties related to shipping industry to work together in technology and operation to achieve the ‘Decarbonization Target’ on time.

2.2.2. Low carbon development status of the maritime industry in China

At present, IMO and some developed countries have made some achievements in low-carbon emission reduction of maritime industry. China is a big shipbuilding, shipping and port country, with the implementation and update of International Low-carbon regulations, China's maritime industry is facing great challenges. China's government, relevant institutions and shipping enterprises have actively responded, formulated relevant laws and regulations and specific objectives and measures, and achieved preliminary results in low-carbon emission reduction.

1. Port emission reduction

In the past, due to the excessive pursuit of economic benefits in the development of China's ports, the environmental pollution in the port area has become increasingly prominent and has gradually become an important factor hindering the sustainable development of society. The pollution of port area is mainly caused by port operation and ship emission. Port and ships have the characteristics of high emission and high energy consumption. At the same time, in the process of operation, inferior diesel oil is often used, and the sulfur content of these diesel oil is also much higher than that of vehicle diesel oil. Moreover, the engine is often not equipped with filtration or treatment device, resulting in many pollutants in the combustion process.

At present, with the importance of emission reduction, the capacity of emission reduction has been greatly improved. Emission reduction technologies can be divided into two categories: one is pollution source control technology, such as using clean energy, shore power transformation, using low sulfur fuel oil technology, and the other is pollutant treatment technology, which can reduce the degree of air pollution through the treatment of pollutants, such as terminal treatment, oil and gas recovery, etc. However, due to the limitation of our country's technology level, the investment of related infrastructure and equipment in pollution prevention and control is insufficient, resulting in low utilization rate and waste of resources.

2. Shipping emission reduction

Carbon dioxide produced by burning fuel is the main source of carbon emission in maritime industry during domestic and international navigation. At present, Chinese shipping enterprises are actively responding to emission reduction policies, such as navigation at a low speed, using clean energy and researching the environmental protection engine, etc. It can’t be denied that China has made good progress in promoting the application of low and zero emission fuels and technologies in recent years, while the strictness is far lower than European countries in terms of emission reduction standards and policy implementation.

3. Policy development

China's policy has always attached great importance to the emission reduction of the maritime industry. According to the "12th Five-Year Plan", by 2015, the energy consumption per unit turnover of shipping and transportation goods will be reduced by 15% compared with the level in 2005, and the carbon emission will be reduced by 16% (National Development and Reform Commission, 2012). The "13th Five-Year plan" further strengthens the measures of energy conservation and emission reduction in the shipping industry, requiring the transportation industry to reduce its CO2 emission intensity by 7% by 2020 compared with that of five years ago, and the energy consumption per unit turnover of shipping industry by 6% compared with that of 2015. The newly "14th Five-Year Plan" even puts forward higher requirements for emission reduction of maritime industry, leading the concept of "carbon peaking, carbon neutralization" into the maritime industry.

2.2.3. Main problems in low carbon development of China's maritime industry

Personally, China has made a great breakthrough in the emission reduction technology of ships and port design, and the use of clean energy is also increasing promotion and utilization. But, at present, China is still facing quite a few problems in order to keep pace with European countries in developing low-carbon shipping. That means, China is still facing the problem of poor development in the 'soft environment' of maritime industry related to controlling emission of GHG. More specifically, there is still few legal systems of GHG reduction by sea transportation, no complete systems formed between each other, and the scope of domestic law transformation of international conventions also needs to be widen.

1. Low effect of the law

At present, the domestic laws and regulations related to the emission reduction of marine greenhouse gases include <*Regulations on maritime administrative penalty*>, <*Regulations on inspection of ships and marine installations*>, etc.

Besides, China Classification Society has issued the <*Interim Provisions on awarding additional energy efficiency marks for domestic seagoing ships*> and <*green ship code*>. Moreover, China is also planning to draft the law on coping with climate change and has passed the law on the prevention and control of air pollution and other legal provisions. The following content will elaborate the shortcomings of these legal systems.

The law of <*Regulations on maritime administrative penalty*> and <*Regulations on inspection of ships and marine installations*> are currently departmental rules at the level of effectiveness, which means they are lower than the law in the level of effectiveness. There is no doubt that this will affect the authority of the provision, which may affect the effectiveness of its implementation. Although <*Interim Provisions on awarding additional energy efficiency marks for domestic seagoing ships*> and <*green ship code*> have made achieved a high degree of matching with international conventions and they can achieve the desired results, while the effectiveness level of these rules is still very low and cannot form the legal force to regulate domestic marine greenhouse gas emission reduction. In addition, the rules formulated by China Classification Society have not yet defined its legal attribute, so the relevant marine emission reduction regulations issued by China Classification Society cannot clearly define the effectiveness rank. That means, they will also encounter lots of difficulties in execution during practical operation.

2. No systematic legislation

At present, those regulations relation to emission reduction of GHG have not yet formed a complete legal system, the relevant legislation on marine emission reduction is scattered in the provisions of <*measures for the operation and management of Clean Development Mechanism projects*>, <*technical rules for statutory inspection of international seagoing ships*>, <*Interim Measures for the* *administration of carbon emission trading*>, etc. Besides, some marine greenhouse gas emission reduction regulations are scattered in laws or departmental regulations, and some marine greenhouse gas emission reduction regulations are issued by classification society. However, the applicable effect of marine greenhouse gas emission reduction regulations issued by classification society is not clear. Therefore, at present, China's domestic marine greenhouse gas emission reduction legal system has not yet formed a complete system, which will bring about specific application problems for China’s marine emission reduction practice. So, we can make a conclusion that the current domestic legislation situation of marine greenhouse gas emission reduction is in a relatively scattered and chaotic state, and the relevant marine greenhouse gas emission reduction regulations have not yet formed a complete legal system.

Chapter 3 Application and obstacles of "Subsidy" and "Cap-and-Trade" in the maritime industry

3.1 Analysis on "Cap-and-Trade"

In previous paragraphs, through policy and data analysis, we have a clear mind about the necessity of emission reduction in maritime industry, based on policy and data analysis. As explained earlier, one of our objectives is to comprehend long term difference between a simple carbon subsidy and cap-and-trade schemes. In this section, we will first examine most common cap-and-trade schemes, giving indications on the mechanism and application of it.

3.1.1 Theoretical basis

The theory of pollution emission trading originates from 'Coase Theorem'. Coase studies believe that once the property rights of a certain commodity or service can be clearly defined, a free economic market can ensure the optimal allocation of resources. Under this theoretical basis, if the pollution emission rights can be defined by the government or relevant departments, enterprises can trade pollution emission rights freely , so as to achieve the optimal use of the pollutant emission rights resources. This kind of pollution control method is different from the previous government's single emission prohibition law but based on the total amount control to activate the legal trade between polluters. These basic theories of pollution emission trading promote the formation of carbon emission trading. (Coase, 1960)

According to the principle of cap-and-trade, what the government needs to do is to issues free carbon emission quota to enterprises in the carbon trading system. With that, the enterprises need to purchase extra carbon quota from other enterprises in the carbon trading markets when their carbon quota of enterprises is not enough to cover their actual carbon emissions. That means, enterprises with low marginal emission reduction cost take low-carbon investment activities to reduce carbon emissions; enterprises with higher marginal emission reduction costs can directly purchase carbon quotas, which can not only effectively reduce CO2 emissions, but also promote the research and development of low-carbon technologies and solve the problem of negative externalizes of enterprises with market mechanism. However, the introduction of carbon quota makes carbon emission rights become a part of the marginal cost of products. A reasonable amount of carbon quota will encourage enterprises to reduce the marginal cost of products through carbon emission reduction, but the excessive carbon quota will cause serious unfair market competition.

3.1.2 Analysis on basic principles

Enterprises with different emission reduction costs are the premise of carbon trading. Meanwhile, the government adopts the means of cap-and-trade to control the emission, showed in Figure 6.

So, we suppose there are two shipping enterprise A and B.

The marginal emission reduction costs of enterprise A and B are MC_A and MC_B respectively, the marginal emission reduction cost of enterprise A is lower than that of Enterprise B, that is, $MC_A < MC_B$.

The original carbon emission of these two enterprises was e_1 tons/year. In order to achieve the emission reduction target, the carbon quota obtained by the two enterprises was e_2 tons/year, then, $e_1 > e_2$, so the emission reduction of these two enterprises was e_1-e_2, which was recorded as e_0. At this time, $MC_A(e_0) < MC_B(e_0)$.

The total emission reduction cost of enterprises A and B is the sum of the area of OBe_0 and OAe_0. The emission reduction cost of enterprise A is low, and the marginal emission reduction cost is not higher than P_B and not less than P_A to undertake the emission reduction task (e_A-e_0). When the emission reduction cost of enterprise B is not higher than P_B, the choice is to undertake less emission reduction task (e_0-e_B), meanwhile, (e_0-e_B) = (e_A-e_0).

At this time, the total cost of social emission reduction is the sum of the area of

OCe_B and ODe_A, and the total cost of emission reduction is reduced.

The total emission costs = $S_{OBe0} + S_{OAe0} - (S_{OCeB} + S_{ODeA}) = S_{ADE} + S_{BCE}$

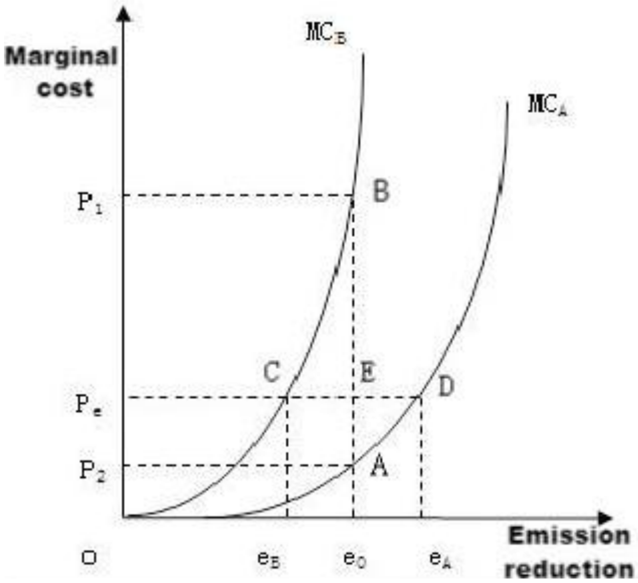

Figure 6 Basic principles of carbon trading

These two enterprises make emission reduction and trading decisions according to their own profit maximization and stop trading until the marginal emission reduction costs of enterprises A and B are equal. The total amount of emission reduction does not change due to the transaction of enterprises. The advantage of emission reduction of enterprise A enables it to undertake more emission reduction and obtain corresponding benefits, while the dilemma of high emission reduction cost of enterprise B can be alleviated in carbon trading. Thus, the two enterprises just allocated the total cost of social emission reduction reasonably, and the emission amount was in line with the total amount set by the government.

In conclusion, carbon trading, as a market mechanism, effectively allocates environmental capacity in emission reduction enterprises in a low-cost and efficient way, so as to minimize the total cost of social emission reduction.

3.1.3 Design steps

Policy of carbon trading, which can achieve a series of results through good mechanism design, including effective results in environmental, economic, and social fields. The following table explained steps for designing a carbon trading mechanism in detail.

Table 2 Steps for Designing a Carbon Trading Mechanism

Steps	Measures
Determine coverage	Determine the industry to be covered Determine the gas to be covered Selection of emission monitoring points Select the entities to be supervised and consider whether they need to be supervised Set the entry threshold
Set a cap	Create a strong data base to determine total emissions Determine the level and type of total emissions Choose the time period to set the total emission and provide the long-term total emission control path
Allocation quota	Matching allocation method and policy objectives Define the qualification and method of quota free allocation, through auction over time Define new entrants, close businesses, and clean up processing methods
Consider using a set off mechanism	Determine whether offsets from uncovered sources and industries within and / or outside the jurisdiction are accepted Select qualified industries, gases and activities Trade off Determine the limit on the use of the offset amount Establish monitoring report verification and management system
Identify flexible measures	Set rules for quota storage Set rules for quota borrowing and early allocation Set the length of reporting cycle and performance cycle
Consider price and cost	Build the basis of market intervention and establish the risk related to it
Ensuring compliance and monitoring mechanism	Define management framework Determine control objectives Implementation of emission report of management and control unit Design and implement punishment mechanism and execution mechanism
Implementation,	Regulate and supervise the market of carbon emission quota trading Determine the implementation time and process of carbon emission

evaluation and improvement	trading system Determine the process and scope of the review Evaluate the carbon trading system and support the review

Resource: Governments' documents

3.14 Structure of carbon trading markets

The structure and types of international carbon market are various, including the regional carbon market established by legislation in EU, New Zealand and other countries or regions, as well as the non-mandatory carbon market promoted by some NGOs and environmental protection organizations. Broadly, carbon trading market can be divided into three categories, as summarized in Figure 7.

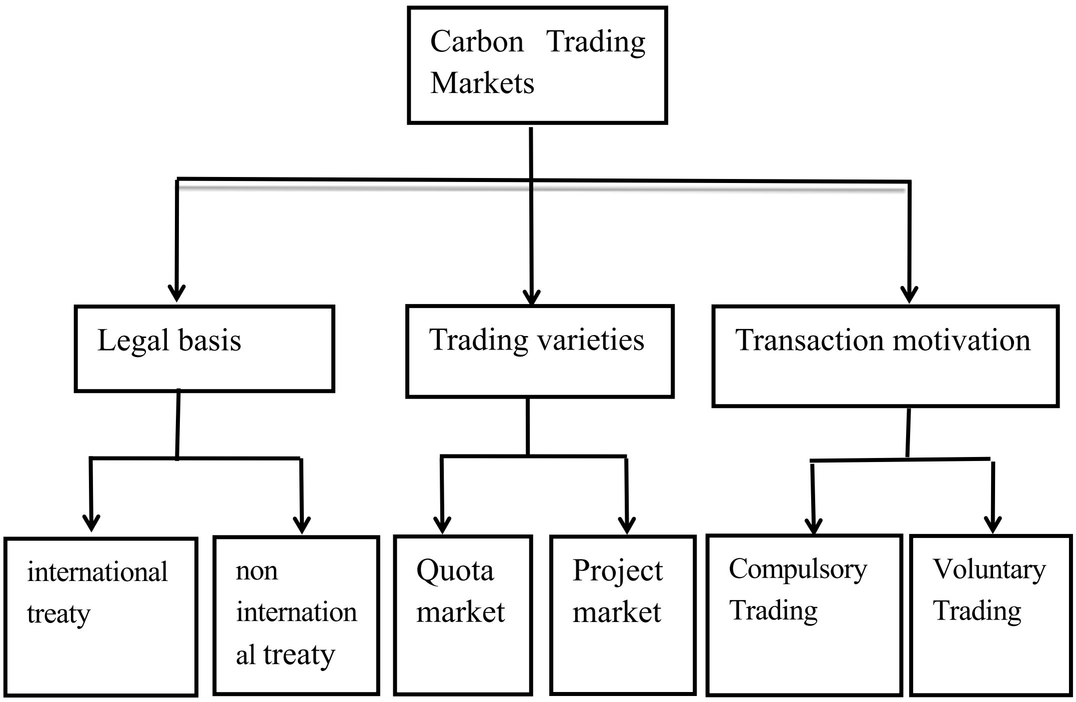

Figure 7 Structure and Classification of Carbon Trading

Firstly, the international carbon trading market can be divided into legal basis, trading varieties and transaction motivation. Countries like European, New Zealand, California and Australian has established carbon trading markets based on Legislation. In addition, other established carbon markets are mainly based on the implementation of international treaties like 'Kyoto Protocol', 'Paris Agreement', etc.

Secondly, carbon market can be divided into mandatory performance market and voluntary emission reduction market according to the mandatory trading of carbon trading market. Mandatory carbon trading market is generally established under the legal framework of national mandatory. To complete the international treaty or for the purpose of ecological protection, these countries have issued a series of relevant laws and regulations. On the other hand, the voluntary carbon emission reduction market is mainly formed by the regional voluntary emission reduction alliance. Through resource emission reduction, enterprises could establish a good social image, and take the initiative to undertake social responsibility to create the brand value of enterprises.

Finally, carbon trading market can be divided into single quota market and single project market according to different types of carbon market quota. The single quota approach is established following the rules of ‘cap-and-trade’, which is the most reasonable way, the most used countries, and the most successful way of carbon market. In addition to the above cities that have established carbon trading markets according to legislation, China’s carbon trading market also adopts the method of cap-and-trade.

3.15 Principle of emission reduction in maritime industry

In order to price carbon emission, government put a tradable limit on the number of allowable emissions, which is called ‘cap-and-trade’. Firstly, under the carbon trading mechanism, carbon quota becomes one of the factors of production. Enterprises in high energy consuming sectors must purchase carbon emission rights in the carbon trading market to meet their own production needs. The cost of purchasing carbon emission rights is fully converted into production cost in the enterprise cost-benefit analysis. Therefore, under the cost pressure, enterprises will tend to adjust the production scale and reduce output. Secondly, when measuring the cost of purchasing carbon emission rights and improving low-carbon emission reduction technology, enterprises tend to increase R & D investment, develop, introduce, and adopt low-carbon emission reduction technology. Enterprises improve energy efficiency through technological innovation and optimize energy consumption structure by replacing fossil energy with clean energy. In addition, under the carbon trading mechanism, carbon quota resources are allocated by the market through the carbon price mechanism, and the backward production capacity and industry enterprises with high energy consumption, high pollution or low efficiency are gradually eliminated by the market under the cost pressure. Chart 4.4 showed the acting path of carbon trading mechanism.

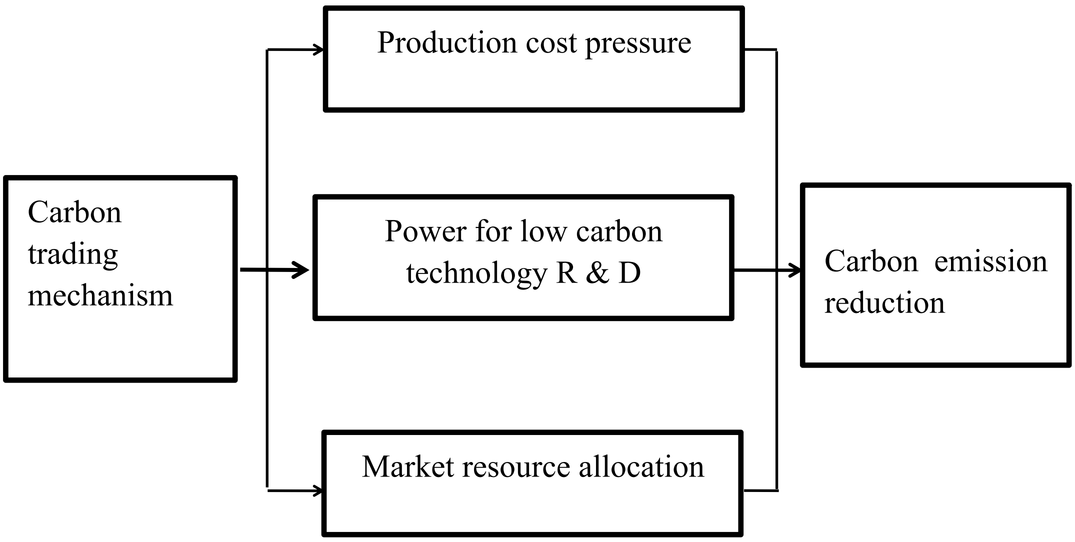

Figure 8 Acting path of carbon trading mechanism

When we take the cap-and-trade into account in maritime industry, we must take the particularity of maritime industry into consideration. Fuel price is artificially raised by the purchases of permits, or right to pollute, at flexible price. The number of emission permit is capped at a global level. Such global level could be territorial, or sector based. Methods determining such cap differ in various systems; limit on emissions could be fixed or progressively decreased year after year.

Based on the above theoretical basis of cap-and-trade, taking emission reduction of maritime industry as an example, the principle of carbon trading includes the following aspects:

(1) Firstly, set the overall carbon emissions of the maritime industry in a certain period in the future through negotiation.

(2) Based on obtaining the total amount of carbon emissions of the shipping industry in the future, the industry will allocate part of the free quota to shipping enterprises through a certain carbon quota allocation method. The fairness of this allocation depends on the allocation method. The specific allocation quota depends on the support of many energy consumption data of the shipping industry. The amount of free quota is lower than the average development level of the industry.

(3) After the shipping enterprises get the free quota, they will form a kind of development restriction, resulting in three results: ①shortage of carbon quota; ②Carbon quota surplus; ③the carbon quota is equal to the actual emissions of shipping enterprises.

(4) At this time, those shipping companies who are committed to improving transport efficiency through technical and operational emission reduction measures will get more quota than the actual carbon emission level. On the contrary, shipping enterprises with low emission reduction will face the risk of carbon quota shortage. In order to offset the risk of quota shortage, they can purchase the insufficient quota from the enterprises with surplus carbon quota in the carbon trading market or make up for it in the process of government carbon quota auction.

In this way, the shipping enterprises that invest human and material resources to reduce emissions can obtain certain financial compensation from the carbon market, so as to carry out the next round of emission reduction work. Enterprises with long-term quota shortage must suffer from the economic loss of purchasing carbon quota to stimulate their emission reduction. If they have been in shortage, they will face the corresponding punishment from the regulatory authorities.

3.16 Application of cap-and-trade

To comprehend practical effect of cap-and-trade on the maritime industry, we will make further analysis on the application of international cap-and-trade system and the domestic cap-and-trade system, respectively.

Firstly, the Shanghai emission trading scheme, in its initial stage, includes maritime emissions, which is the largest and the closest cap-and-trade scheme. Shipping companies emitting more than 10,000 tons of CO2 or 5,000 tons coal equivalent per year are requested to pay a charge on emissions. Price on emissions can change, while a controlling entity limits variations of carbon price to 10% per day. (See Shanghai Development and Reform Capital, 2016 and ICAP, 2018).

Another existing ETS scheme called EU-ETS is not related to maritime currently. Still, the EU's proposed inclusion of shipping in its Emission Trading Scheme from 2022 and the Sea Cargo Charter initiative. That means, ETS will gradually cover, expand the scope of use in the field of maritime. Besides, the existing ETS schemes may also influence design of maritime scheme in the future such as dynamic cap on emissions used in EU and Californian.

3.2 Analysis on "Government Subsidy"

After the introduction of cap-and-trade, we aim to understand characteristic and applications of carbon subsidy. As explained in the introduction, carbon subsidy is another power policy used by government to control carbon emission behavior of enterprises. Different from the binding policy of cap-and-trade, carbon subsidy is a kind of incentive policy.

3.21 Reduction Mechanism of "Carbon Subsidy"

Government subsidy refers to the government's financial support to individuals, organizations, enterprises, and other subjects, which is free of charge. Subsidies can promote enterprises to adapt to new policies and laws, helping enterprises improve their competitiveness. Subsidies include direct subsidies and indirect subsidies. The former is directly subsidized by cash or in kind, while the latter is subsidized by tax return. Compared with other fiscal policy tools, subsidies are more commonly used in carbon emission reduction because of their efficiency and small implementation resistance. In the early stage of emission reduction, enterprises must face many obstacles to reduce emissions such as immature emission reduction technology, lack of emission reduction experience as well as insufficient understanding of carbon market. At this time government subsidies are used to improve the motivation of enterprises.

The government subsidizes the enterprises according to actual purification capacity. The more emission reduction, the more government's subsidies they gain. The incentive of low-carbon production from the government will make more enterprises implement internal emission reduction technology, introduce advanced emission reduction technology, purchase emission reduction equipment, and achieve higher output, to achieve better overall emission reduction effect. However, the subsidy policy has a higher demand for the government's financial support. If the subsidy amount is too low, it will not play an incentive role. If it is too high, it will increase the government's financial burden.

3.22 Application of "Government Subsidy"

To encourage the adoption of low carbon technology, some government subsidize consumers on their consumption behavior. For example, consumers who bought a Chevy Volt in the USA were eligible for $7500 tax rebates. Based on the Energy information Administration in 2016, the federal government of the USA spent about $14 billion in energy subsidies and support. Subsidies for renewable energy were over $6 billion. As estimated, about 80 percent of the 2016 renewable subsides came in the form of tax breaks. In China, government has also issued a series of policies to encourage enterprises to reduce carbon emissions. For example, in May

2015, the Ministry of Finance issued the 《notice on the financial support policies for the promotion and application of new energy vehicles in 2016-2020》, which carried out the promotion and application of new energy vehicles nationwide. The central government gives subsidies to consumers who buy new energy vehicles. The subsidy standard is mainly based on the effect of energy saving and carbon emission reduction, and implements the retrogression system, considering the production cost, scale effect, technological progress, and other factors

On the other hand, fuel subsidies and green shipping technology subsidies are widely used in the shipping industry. Many countries provide massive subsidies to fossil fuels especially for the LNG, which can be referred to as subsidy on carbon emission. Not only China, but also other European countries are all trying to expand subsidies for LNG due to its powerful intensity of emission reduction, nearly 23% of carbon dioxide emission reduction.

3.3 Obstacles to implement cap-and-trade

3.31 Loopholes in the trading mechanism

At present, there are some problems in the work of carbon trade in China, such as the relatively lagging legislation and low legal effect. As the top-level system design, <*The Law of the People's Republic of China on Climate Change Response*> and the <*Interim Regulations on the administration of Carbon Emission Trading*> are in the stage of soliciting opinions. Besides, <*The work plan for Controlling Greenhouse Gas Emissions in the 13th five-year plan*>, <*The Interim Measures for the administration of Carbon Emission Trading*> and <*The Interim Measures for the Administration of Greenhouse Gas Voluntary Emission Reduction Trading*>, which have been issued, are all normative documents, lacking authority in implementation.

At the same time, as a systematic work, carbon trading has insufficient coordination among relevant departments, central and local governments. The national development and Reform Commission (NDRC) has been assigned to the

Ministry of ecological environment to deal with climate change, while there are still some problems, such as policy transition, department collaboration, and top-down improvement and rationalization of the corresponding management mechanism.

3.32 Low carbon trading price and insufficient liquidity

Under normal circumstances, the carbon price formed by a stable carbon market should show a gradual upward trend due to the incremental effect of marginal emission reduction cost. However, the performance of carbon price in China's carbon trading pilot areas is not stable and the carbon price difference between regions is large in recent years. For example, during September 10-20, 2019, the lowest carbon price in China's carbon trading pilot areas is Chongqing (0.48 euro / ton), and the highest is Beijing (11.19 euro / ton). During the same period, the spot price of EU carbon is basically stable at 25.44-27.02 euro / ton, far exceeding the domestic carbon price. The main reasons are summarized as follows: Firstly, the carbon trading market liquidity is insufficient, and the price discovery is insufficient, the carbon trading and carbon asset management consciousness of emission control units is not strong, and their enthusiasm is not high. Secondly, the participation of individuals and investment institutions is insufficient, and the market activity is not enough. Thirdly, it cannot objectively reflect the real marginal cost of carbon dioxide emission reduction and supply and demand. Finally, there is a lack of price stability mechanism in the carbon market.

3.33 Total carbon quota is out of line with emission reduction target

As we all know, it is hard to realize the targets of emission reduction if setting a quite loose carbon emission quota, while, setting too low is easy to cause great impact on the operation of trading entities. Firstly, the total amount of carbon emission quota is out of line with the carbon emission reduction target. The carbon quota in the pilot area of carbon trading is not able to link up the local medium and long-term carbon emission reduction targets. Secondly, the initial allocation of carbon quota lacks scientific proof and unified calculation standard. The carbon trading pilot areas mainly adopt the methods of independent declaration by emission control units and historical emission accounting, while some enterprises conceal the declaration and deliberately reserve space for later emission reduction, the allocation standards, methods, and procedures are opaque at the same time. Thirdly, it is not scientific to determine the proportion of free distribution and auction of carbon quota. Carbon trading pilot areas are mainly free distribution, and the auction proportion is generally less than 5%, which is lower than 60% of which in EU ETS. In addition, the application of the two methods is not differentiated by industry risk difference and the quota system of market regulation is not perfect.

3.34 Obstacles in maritime industry

We can find an interesting phenomenon that countries and international organizations have been constantly improving the overall legal system of carbon emissions trading, while there is no corresponding development in maritime industry in this aspect. One of the reasons for this kind of puzzle is that there is a great difference in implementation at the legal level in terms of monitoring carbon emission between maritime industry and other industries

The main participant of carbon trading system in most industries is relatively clear. For example, the participants of the joint implementation mechanism under the Kyoto protocol are Annex I countries and economies in transition, and the participants of CDM regulation is Annex I countries and non-Annex I countries. There are similar advantages between these industries. Firstly, the total amount of carbon emissions is easy to determine; secondly, the main body of carbon emission is easy to determine; thirdly, the main body of carbon emissions generally has only one nationality or is a country, and the trading effect can directly affect the country.

However, the above advantages will no longer exist if we look at shipping in the same way. First of all, it is difficult to determine the total carbon emissions in the maritime industry. For example, if a chemical plant on land discharges pollutants into the sea, it is difficult to tell whether the carbon in the sea comes from the shipping industry or other fields. Besides, the carbon dioxide emitted by ships to the sea is likely to be mixed with that emitted by land-based sources. Secondly, even if the total amount of emissions is determined, due to the existence of 'Flag of Convenience', the flag state does not coincide with the country that enjoys the interests of ship operation, and the effect of trading cannot be determined to which country. On the other hand, the ocean is moving all the time, and ships are also moving when they are sailing. It is difficult to explain whether the carbon in a certain sea area comes from the direct emission of ships or the flow of the ocean and it is hard to be fair to calculate such a carbon amount in a certain subject's emission reduction quota, which limits the development of carbon trading in maritime industry.

Meanwhile, there are also many practical obstacles in the application of cap-and-trade in the maritime industry. Shipping enterprises, especially in such kind of situation when the price of carbon emission quota is low, will give priority to buying additional emission quota to meet the requirements, rather than investing in improving the energy efficiency of new ships and existing ships. In this way, it will directly reduce the willingness of enterprises to invest in reducing carbon emissions and not take advantage of long-term low-carbon economic development.

As we all know, carbon emission quota is an integral part of cost for shipping companies. Perhaps, such costs are minimal for large shipping companies, because the more cargo they are carrying the lower the cost per unit of goods. However, that is not the case for the small shipping companies, they must take on more cost burden. On the other hand, different types of ships transport different goods, and their sensitivity to carbon price is also different, which depends on market situation and profit of goods.

Chapter 4 Selection of optimal emission reduction strategy for maritime industry based on Analytic Hierarchy Process

4.1 Basic principle and steps

Analytic hierarchy process (AHP) is mainly used to optimize the selection of complex or fuzzy phenomenon, which is very suitable for the phenomenon that is difficult to fully quantitative analysis. The steps are listed as follow.

Step 1. Constructing the hierarchical structure mode.

Step 2. Constructing the judgment matrix of each level.

Step 3. Carrying out the consistency test after sorting the hierarchical list.

Step 4. Finally, carrying out the consistency test after the total sorting of hierarchy is completed. The level can be divided into the following three levels.

(1) Top layer: there is only one factor in this layer, which is the predetermined target result, so the top layer is also called the target layer. (2) Intermediate layer: as the name suggests, the intermediate layer is the intermediate process to be completed in order to get the target layer. It is generally composed of multiple levels. These levels are the criteria and sub criteria to be analyzed, so it is also called the criteria layer. (3) Bottom: including the measures or schemes to be selected in order to get the highest level. The number of levels depends on the complexity of the problem. Generally speaking, the number of levels is not limited. However, for each layer of elements, the number of elements in the next layer cannot exceed nine. The main reason is that if the number of elements in the next layer is too many, the complexity of the problem will increase, and it is not easy to get the correct conclusion.

Table 3 synthesis table of hierarchical total sorting

LA / LB	A_1	A_2	…	A_n	Total sorting weight of layer B

B_1	b_{11}	b_{12}	…	b_{1n}	$\sum_{j=1}^{m} b_{1j} a_j$
B_2	b_{12}	b_{22}	…	b_{2n}	$\sum_{j=1}^{m} b_{2j} a_j$
…	…	…	…	…	…
B_n	b_{n1}	b_{n2}	…	b_{nm}	$\sum_{j=1}^{m} b_{nj} a_j$

After dividing these layers, we can get the vector of each layer relative to the upper layer. In order to get the weight of the highest-level elements in the criterion layer and the weight of the lowest level scheme to the target, so as to select the scheme. In this paper, the upper level (layer A) of the total ranking weight of the included factors is set as a_1, a_2, …, a_m, and the next level (layer B) of the included factors is set as B_1, B_2, …, B_n, to introduce the weight proportion of multiple factors in layer B, that is, to calculate the total ranking weight of each factor in layer B. the calculation method is shown in table 3.

To check the consistency of the total ranking of the levels, the process is consistent with the order of the highest level, middle level, and lowest level, which is to do the ranking research from high to low. The reason for ranking from high to low is that all levels have passed the consistency test after single ranking. However, in the process of sorting, consistency will accumulate with the increase of hierarchy, which greatly increases the possibility of inconsistency in the result. In this paper, we assume that the factors related to j and A are compared with the judgment matrix in layer B in pairs, and the result of consistency test in single ranking is that the corresponding average random consistency index is R, then the proportion of total ranking random consistency in layer B is CR.

Since we will face all kinds of problems in the actual index analysis, the information we get is asymmetric, so there are some errors in the consistency test. As shown in Table 4.

Table 4 RI values of random matrices of order 3 ~ 13

Number of indicators	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.51	0.89	1.12	1.25	1.35	1.42	1.46	1.49	1.52	1.54	1.56

Generally, the consistency ratio (CR) is used as the criterion of consistency test

$$CR = \frac{CI}{RI}$$

The maximum λ_{max} eigenvalue can be obtained from the table, and then the RI value can be found from Table 4-2 according to the order of the matrix; Calculate the CR value, if CR < 0.1, then pass the test, otherwise, the judgment matrix will be adjusted and recalculated.

4.2 Construction of evaluation system

According to the above theoretical analysis, this paper designs a three-tier evaluation index system for the shipping industry emission reduction strategy and establishes a hierarchical structure model. It is convenient for comprehensive evaluation of the two schemes. The first level of the system is target level A: the optimal alternative emission reduction strategy of shipping industry; The second level is criterion level, which is divided into four categories: cost consumption index B_1, pollutant emission index B_2, policy and regulatory index B_3, and environmental protection laws and regulations index B_4, each category has sub index level, which is subdivided into 20 items; The third layer is scheme layer C: cap-and-trade and subsidy mechanism. The specific index system is shown in table 5.

Table 5 criteria level evaluation index system

First level index layer	Symbol	Secondary index layer	Symbol

Cost consumption index	B1	Price cost	B11
		Market liquidity	B12
		Emission reduction efficiency	B13
		Changes in comprehensive energy consumption	B14
		Welfare subsidy	B15
Pollutant emission index	B2	Carbon dioxide emissions	B21
		Methane emissions	B22
		Nitrous oxide emissions	B23
		Emissions of hydrofluorocarbons	B24
		Emissions of perfluorocarbons	B25
		Emission of sulfur hexafluoride	B26
		Carbon emission quota	B27
		Actual emissions	B28
Policy and regulatory indicators	B3	Policy guidance and quota system	B31
		Publicity	B32
		Information transparency	B33
		Enforcement	B34
Indicators of environmental laws and regulations	B4	Investment in environmental protection technology improvement	B41
		Compliance of emission standards, laws and regulations	B42
		Effect of Emission reduction	B43

4.3 Calculation of Index weight

4.3.1 Results of Expert scoring

Psychology has proved that for different things with the same attribute, most people can easily judge whether they have the same or not, and usually, people can judge the differences of multiple different things in the same attribute. Usually, the extremum of the number of things that people can distinguish is between 5 and 9, so the 1-9 scale method can correctly reflect people's ability to distinguish. Through many years of practical experience, 1-9 scale method has been proved to be able to reasonably divide the differences of different things in the same attribute. This method has also become a common scoring method used in AHP. In this paper, the classic 1-9 scale method is introduced to determine the importance of indicators by pairwise comparison. The specific scoring rules are shown in table 6.

Table 6 comparison of importance

Serial number	Comparison of influence degree between index I and index J	r_{pq}
1	Both are equally important	1
2	The influence of i is slightly greater than that of j, but it is not obvious	3
3	The influence of i is more obvious than that of j, but not obvious	5
4	The influence of i is more obvious than that of j, but not particularly obvious	7
5	The influence of i is much greater than that of j	9
6	Compromise between two adjacent criteria	2,4,6,8
7	The influence of j is greater than that of i, and the degree of influence is as mentioned above	1/3,1/5,1/7,1/9

The method of determining index weight is mainly divided into subjective weighting method and objective weighting method. Subjective weighting method relies on expert experience to judge, while objective weighting method depends on the degree of variation and correlation of indicators. It is not easy to express the indexes accurately with the data after quantitative processing, so we use the subjective weighting method to determine the weight, which is conducive to reflect the degree of attention of the judges to different indexes. In this paper, Delphi method is used to consult experts. Firstly, the Delphi method was used to design and distribute 60 questionnaires of experts (senior management of shipping industry), and 56 valid questionnaires were collected. Among the returned questionnaires, the questionnaires with the following factors will be regarded as invalid ones and then be shaved: first, the same answers are selected for more than ten consecutive questions; Secondly, similar or opposite answers were filled in the positive and negative questions of personality trait scale; Thirdly, the questionnaire answer is not perfect. Through the effective shaving of invalid questionnaires, a total of valid questionnaires is obtained, which meet the requirements. The specific value of the effective recovery rate of this questionnaire is 93.33%. Then, the questionnaire is summarized and coded to lay a solid foundation for the follow-up empirical research at the information level. Through the summary and processing of the questionnaire information, the judgment matrix is obtained through the pairwise comparison of the indicators. After the expert investigation, AHP is used to analyze and calculate the index weight.

After the target problem is layered, it is necessary to analyze the constituent elements of each level, and the importance of the upper level is measured by weight. Moreover, it is necessary to quantify the data and express these judgment matrices by appropriate numerical values. In this paper, the 1-9 scale method is used to obtain the judgment matrix through pairwise comparison of various factors in the same level, and the constructed judgment matrix needs to meet the formula：

$$\begin{cases} a_{ij} = 1(i = j) \\ a_{ij} = \dfrac{1}{a_{ji}}(i \neq j; i = 1, 2, \ldots, n; j = 1, 2, \ldots, n) \end{cases}$$

According to the analysis of relevant shipping industry experts combined with two emission reduction strategies, the judgment matrix of standard layer is constructed, as shown in table 7.

Table 7 standard layer judgment matrix

	B_1	B_2	B_3	B_4
B_1	1	1/2	6	3
B_2	2	1	9	5
B_3	1/6	1/9	1	1/2
B_4	1/3	1/5	2	1

4.3.2 Weight vector calculation and consistency test

(1) Calculate weight vector

Weight vector of independent decision matrix

We assumed the judgment matrix: $A = [a_{ij}]_{n \times n}$, If $\forall i, j, k = 1, 2, \cdots n$, established $a_{ik} = a_{ij} a_{jk}$, Let A be the consistency matrix. The elements of consistency matrix A can be expressed in the form of $a_{ij} = \frac{w_i}{w_j}$. There are many ways to calculate the weight:

Sum method: according to the property of index, sum the judgment matrix:

$$\overline{w}_i = \Sigma_{j=1}^{n} a_{ij} \qquad i = 1, 2, \cdots, n \tag{1}$$

Then the weight vector is obtained by normalization:

$$w_i = \frac{\Sigma_{j=1}^{n} a_{ij}}{\Sigma_{k=1}^{n} \Sigma_{j=1}^{n} a_{kj}} \qquad i = 1, 2, \cdots, n \tag{2}$$

Root method: according to the above index properties, calculate the geometric average of each line element in the judgment matrix:

$$\overline{w}_i = (\Pi_{j=1}^{n} a_{ij})^{\frac{1}{n}} \qquad i = 1, 2, \cdots, n \tag{3}$$

After normalization, the weight vector is obtained:

$$w_i = \frac{(\Pi_{j=1}^{n} a_{ij})^{\frac{1}{n}}}{\Sigma_{k=1}^{n} (\Pi_{j=1}^{n} a_{ij})^{\frac{1}{n}}} \qquad i = 1, 2, \cdots, n \tag{4}$$

The weight is determined by the judgment matrix *A* of the target layer of the evaluation index system, the cost consumption index B_1, the pollutant emission index B_2, the policy and supervision index B_3, and the environmental protection laws and regulations index B_4.

According to table 4-5, the judgment matrix A of the first level index layer is

$$A = \begin{vmatrix} 1 & 1/2 & 6 & 3 \\ 2 & 1 & 9 & 5 \\ 1/6 & 1/9 & 1 & 1/2 \\ 1/3 & 1/5 & 2 & 1 \end{vmatrix}$$

In the same way, the second level index matrix is obtained as follows,

$$B1 = \begin{vmatrix} 1 & 1/3 & 1/9 & 1/2 & 1/4 \\ 3 & 1 & 1/7 & 1/3 & 1/5 \\ 9 & 7 & 1 & 8 & 5 \\ 2 & 3 & 1/8 & 1 & 1/3 \\ 4 & 5 & 1/5 & 3 & 1 \end{vmatrix}$$

$$B2 = \begin{vmatrix} 1 & 2 & 3 & 3 & 3 & 2 & 3 & 3 \\ 1/2 & 1 & 3 & 2 & 2 & 1/3 & 2 & 1/3 \\ 1/3 & 1/3 & 1 & 1/3 & 1/2 & 1/3 & 1/3 & 1/3 \\ 1/3 & 1/2 & 3 & 1 & 1/2 & 1/3 & 1/3 & 2 \\ 1/3 & 1/2 & 2 & 2 & 1 & 1/2 & 1/2 & 1/3 \\ 1/2 & 3 & 3 & 3 & 2 & 1 & 2 & 2 \\ 1/3 & 1/2 & 3 & 3 & 2 & 1/2 & 1 & 1/4 \\ 1/3 & 3 & 3 & 1/2 & 3 & 1/2 & 4 & 1 \end{vmatrix}$$

$$B3=\begin{vmatrix} 1 & 1/3 & 5 & 1/4 \\ 3 & 1 & 6 & 1/2 \\ 1/5 & 1/6 & 1 & 1/7 \\ 4 & 2 & 7 & 1 \end{vmatrix}$$

$$B4=\begin{vmatrix} 1 & 1/4 & 1/3 \\ 4 & 1 & 1/2 \\ 3 & 2 & 1 \end{vmatrix}$$

(2) Consistency test

After getting the judgment matrix of each dimension, normalize it and test its consistency. Taking the standard layer as an example, the obtained fuzzy matrix is shown in table 8.

Table 8 Normalization results of standard layer

Target	B_1	B_2	B_3	B_4	Row element product	Root of 5th power	Weight	Maximum eigenvalue
B_1	1	1/2	6	3	9.0000	1.7321	0.3025	4.0102
B_2	2	1	9	5	90.0000	3.0801	0.5379	
B_3	1/6	1/9	1	1/2	0.0093	0.3102	0.0542	
B_4	1/3	1/5	2	1	0.1333	0.6043	0.1055	

According to the consistency test of standard layer, the weight of judgment matrix is [0.3025, 0.5379, 0.0542, 0.1055], and the maximum eigenvalue is 4.0102, then,

$CI = (\lambda max - n) / (n - 1) = 0.0034$

$CR = CI / RI = 0.0038 < 0.1$

Therefore, the standard level judgment matrix constructed in this paper meets the requirements. And so on, each criterion layer is treated as above. It can be obtained that the test results have passed the consistency test.

4.4 Total sorting and selection results

According to the results of AHP, the weights of each factor in the criterion layer are shown in table 9.

Table 9 Criteria layer weight table

First level index layer	weight	Secondary index layer	weight	Comprehensive weight
Cost consumption index	0.302	Price cost	0.043	0.013
		Market liquidity	0.062	0.019
		Emission reduction efficiency	0.597	0.18
		Changes in comprehensive energy consumption	0.094	0.029
		Welfare subsidy	0.205	0.062
Pollutant emission index	0.538	Carbon dioxide emissions	0.257	0.138
		Methane emissions	0.113	0.061
		Nitrous oxide emissions	0.044	0.024
		Emissions of hydrofluorocarbons	0.076	0.041
		Emissions of perfluorocarbons	0.076	0.041
		Emission of sulfur hexafluoride	0.195	0.105
		Carbon emission quota	0.096	0.052
		Actual emissions	0.143	0.077
Policy and regulatory indicators	0.054	Policy guidance and quota system	0.145	0.008
		Publicity	0.313	0.017
		Information transparency	0.047	0.003
		Enforcement	0.494	0.027
Indicators of environmental laws and regulations	0.106	Investment in environmental protection technology improvement	0.124	0.013
		Compliance of emission standards, laws and regulations	0.359	0.038

		Emission reduction effect	0.517	0.055

It is obvious from table 9 that in the project, the primary indicators are cost consumption indicators and pollutant emission indicators, accounting for 30.2% and 53.8% respectively. The second level factors are price cost, carbon dioxide emissions, sulfur hexafluoride emissions, actual emissions, welfare subsidies and methane emissions. The weight of price cost is 0.043, which is the largest in all the second level indicators. This is mainly because in the shipping industry, the priority is generally the cost problem. Only when the cost can be reduced, can we optimize the allocation of capital resources. The weight proportion of emission reduction efficiency is also very large, which is mainly due to the analysis of the difference between carbon trading and subsidy mechanism. The biggest difference lies in the efficiency of emission reduction. For the maritime industry, the policy of cap-and-trade can make the optimal production quantity of production and operation activities reach the best proportion in the cooperative emission reduction projects in the middle, upper and lower reaches of the supply chain, The subsidy mechanism can play a significant role in promoting the emission reduction effect of shipping industry in the initial stage.

After determining the judgment matrix, we use the mathematical software MATLAB to get the total ranking, as shown in table 4-8. It can be found that in the cost consumption index, policy and regulatory index, the score of carbon trading is higher than that of subsidy mechanism, while the score of pollutant emission index and environmental protection law and regulation index is lower than that of subsidy mechanism, and the total score is still the best choice for shipping industry, which shows that the total ranking value of carbon trading is 0.3952, The subsidy mechanism is 0.3696, which is far less than the ranking weight of carbon trading.

Table 10 General ranking table

<table>
<tr><td colspan="2">Criterion</td><td>Cost consumption index</td><td>Pollutant emission index</td><td>Policy and regulatory indicators</td><td>Indicators of environmental laws and regulations</td><td rowspan="2">Total ranking weight</td></tr>
<tr><td colspan="2">Criteria layer weight</td><td>0.302</td><td>0.538</td><td>0.054</td><td>0.106</td></tr>
<tr><td rowspan="2">Scheme layer Single sort Weight</td><td>Cap-and-trade</td><td>0.6694</td><td>0.2385</td><td>0.5667</td><td>0.6524</td><td>0.3952</td></tr>
<tr><td>Subsidy</td><td>0.6250</td><td>0.3331</td><td>0.4695</td><td>0.6667</td><td>0.3696</td></tr>
</table>

From table 10, we get the weight of the influencing factors of shipping industry selection. At the same time, in table 4-8, we find that the optimal emission reduction strategy is carbon trading, which is also in line with the results of our theoretical analysis and proves that our model is reliable.

Chapter 5 Policy implications

5.1 Author's recommendation for "Cap-and-Trade"

5.11 Improve the supervision and management system for pollution sources

To make medium as well as long term emission reduction targets and measures into law, the government needs to put more effort into policy making. In the process of constructing the legal system of shipping carbon emission trading, it is not only necessary to constructing shipping carbon emission reduction laws and regulations system, but also stipulate that the coastal countries affected by the carbon dioxide emitted by ships can claim part of the price of carbon trading by providing evidence to make up for the loss caused by pollution. For example, the port authority of a coastal state may be authorized by law to notice vessels calling at ports, loading and unloading cargo at ports to provide and record information on their vessels, cargo, and fuel oil. In a certain period after that, if a coastal country finds that its sea area is suffering from more serious carbon pollution, it can find out the most serious emission subject of its sea area environmental pollution according to the records, and the recorded information can be used as legal evidence. On the other hand, if it is difficult to determine one or several specific emission entities, the emission entities with more emissions and frequent access to ports can be required to bear certain fair responsibilities.

5.12 Improve the price system of carbon trading

In the design of transaction price, we should develop the market self-regulation mechanism under the guidance of the government, formulate trading rules to prevent monopoly in the trading market, build a trading information platform, enhance the symmetry of information, and track and supervise the trading of indicators. Through legislation and other means, we can effectively stop the abuse and illegal transfer of emission targets and put an end to deliberate hoarding and other market disrupting activities. Besides, the responsibility for breach of contract should be clarified, and the enterprises with excessive emissions should be severely punished.

5.13 Establish a fair total amount distribution system

Emission quota allocation is the primary market of shipping carbon emission trading mechanism. Its policy goal is to implement the total emission target, distribute the initial emission right fairly, and establish the primary emission market led by the government. In this process, the main participants are the government and polluters, and they are led by the government. The core problem to be solved is the fairness of indicator allocation. The government needs to formulate a unified total indicator allocation method based on the principle of fairness and justice, so as to ensure the specific implementation of emission reduction tasks to the source and provide a fair environment for enterprises to abide by the law and implement emission reduction responsibilities. At the same time, this is also the basic condition for the formation of a dynamic secondary market.

5.14 Use the experience of aviation industry

In European Union(EU), the legislation to include aviation in Emissions Trading System(EU ETS) was adopted in 2008. Cap-and-trade used in the aviation industry is more mature and stable compared with the shipping industry. On the other hand, there are many similarities between shipping and aviation. So, hopefully, we can borrow from the aviation industry to find out some revelation to improve cap-and-trade in maritime industry.

Currently, there are several ways to reduce emissions in the international aviation industry: Aircraft technology improvement (Technical aspects), sustainable aviation fuel (Energy aspects), Operational improvement (Mechanism) and CORSIA (Market mechanism). CORSIA serves as a kind of carbon offsetting and emission reduction mechanism in international aviation, which is mainly implemented by the participants to purchase the emission reductions generated by the recognized voluntary emission reduction mechanism to offset the excess carbon emissions of their international aviation activities. Compared with cap-and-trade used in maritime industry, these two emission reduction policies have very similar means.

As far as I'm concerned, in order to set a standard quota baseline for carbon emission, the EU has already grasped the situation of the European economic area before adopting the EU ETS in aviation industry. On the other hand, there is only one pilot of cap-and-trade in Shanghai for maritime industry. That means, the benchmark value of Shanghai is only applicable to itself. If the cap-and-trade for maritime industry is to be developed in the future, the data source needs to be expanded and prepared in advance.

During the period of implementation, IMO and EU have been in a state of game. It is difficult to balance the interests of both sides, especially the popularity of EU-ETS may endanger the authoritative position of IMO in the process of shipping emission reduction. In this regard, we can fully refer to the game between EU and ICAO in the process of EU- ETS implementation in aviation industry.

5.2 Author's recommendation for "Carbon Subsidy"

There are two purposes of government subsidies for port and shipping enterprises: one is to improve the competitiveness of enterprises focusing on environmental protection and clean energy, the other is to encourage enterprises to independently develop low-carbon technologies through the subsidy mechanism. So, in my opinion government subsidies should focus on energy and low-carbon technologies.

Subsidies for clean energy, replaced for carbon-contained fuels such as Biofuel, Methanol, Battery Hybrid and LNG, will greatly improve the market share of clean energy. On the other hand, for ports, government subsidies should force on the use of electricity instead of fossil fuel. As a result of that, the carbon fuel sales will fall, leading to the falling of carbon emissions, and achieve the emission reduction goal.

Subsidies for technology research and development are more important because technology is the fundamental driving force for the development of low-carbon economy. Enterprises are the main body of low-carbon R & D. what the government needs to do is to encourage enterprises to be willing to become the main body of low-carbon technology R & D through the subsidy mechanism and enhance the ability of enterprises to resist various risks in technological innovation.

Chapter 6 Conclusion and extension

6.1 Conclusion

In this paper, a comprehensive analytical framework of Cap-and-trade and Subsidy was presented to identify the effect of these two policies on the emission reduction of maritime industry. In this framework, an Analytic Hierarchy Process method was employed to assess the optimal emission reduction strategy for shipping industry. We can draw a conclusion from the model that Cap-and-trade can make the optimal production quantity of production and operation activities reach the best proportion in the upstream and downstream cooperative emission reduction projects of the supply chain, and the subsidy mechanism can play a significant role in promoting the emission reduction effect of the shipping industry in the initial stage. Hence, subsides can be serve as a short-term solution. In the long term, the policy of cap-and-trade is required to reduce the total CO_2 Emissions from ships and ports' operations. For the government, their annual subsidy budget to the port, unit electricity price subsidy, diesel fuel price all has impacts on the overall subsidy efficiency. Besides, governments' subsidy on technique for reducing CO_2 can play a good leading role in low-carbon shipping in the early stage of emission reduction. On the other hand, as a long-term policy means to reduce carbon emission, it is better for governments to constantly adjust macro policies to give full play to the incentive role of cap-and-trade and pay enough attention to it.

6.2 Future research orientations

Of course, there are still some inevitable shortcomings worth further studying in this dissertation. The research framework proposed in this paper are still theoretical, besides, few cases is used to prove the result of this paper. In addition, a series of difficulties still need to be solved. For example, it is ambiguous how does incentive mechanism of cap-and-trade and subsidy work in maritime industry, which needs further study.

In the further, we believe that the policies of Cap-and-trade and Subsidy used by government will become more and more mature. Hopefully, the development of these two policies will promote the growth of derivative green shipping finance such as Carbon Management Consulting, Carbon Element Test, Carbon trading, Carbon trusteeship, Carbon financial services and Carbon Asset Development.

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Number	Survey items	Marks				
		5	4	3	2	1
	(1) Cost consumption index					
1	The price cost					
2	Market liquidity					
3	Efficiency of emission reduction					
4	Change of comprehensive energy consumption					
5	Welfare subsidy					
	(2) Pollutant emission target					
1	Carbon dioxide emissions					
2	Methane emission					
3	Nitrous oxide emissions					
4	Hydrofluorocarbon emissions					

Appendix

Dear experts：

Hello! To fully understand the reasonableness of the shipping industry's choice of emission reduction strategies, we conducted an online survey focusing on common indicators in carbon trading and subsidy mechanisms. We would like to thank you very much for participating in this survey as a leading expert in the evaluation of emission reduction strategies in the shipping industry. Please kindly provide your views and opinions and hope to get your support. This questionnaire is the marking question. You can fill in the points in the form. The information you provided is very helpful for the research. I will strictly fulfill my confidentiality commitment and will not disclose your personal information. Please fill in the information truthfully.。

Thank you for your support! I wish you good health and all the best!

Evaluation content (The questionnaire is presented in the form of multiple-choice questions, with different numbers representing different degrees of importance, of which, 5= very important, 4= relatively important, 3= average, 2= not very important, and 1= not at all important. Please tick √ on the corresponding number on the right of the index according to your own importance.)

5	Perfluorocarbon emissions					
6	Sulfur hexafluoride emissions					
7	Carbon emission quota					
8	Actual discharge					
	(3) Policy and regulatory indicators					
1	Policy guidance and quota system					
2	publicity					
3	Information transparency					
4	Enforcement					
	(4) Environmental laws and regulations indicators					
1	Investment in environmental technology improvement					
2	Compliance with emission standard laws and regulations					
3	Effect of emission reduction					