

# Research on Reducing Ship Carbon Emission for Shipping Enterprises

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## Abstract

In recent years, emissions of greenhouse gases such as carbon dioxide have been increasing gradually, bringing a series of environmental problems like global warming, which has caused great concern of the international community. With the continuous development of the world economy and trade, the number of vessels and tonnages increase continuously, and the carbon emissions reduction of the shipping industry is imminent. The International Maritime Organization and the European Union have issued relevant laws and regulations in order to control carbon dioxide emissions. Based on the characteristics of ship carbon emissions, this paper systematically analyzes the current status of carbon emissions from the shipping industry, policies and regulations related to carbon emissions, and combines the actual operation. Proposed solutions aimed at meeting the IMO's requirements for reducing ship carbon emissions in 2025 while improving the economics of ship operations, and providing corresponding theoretical support and suggestions for shipping companies and managers in the future.

## Keywords

Low carbon emission; Vessel; Economy.

## 1. Introduction

The development of the world economy brings about a series of resource and environmental problems, among which the global warming caused by the massive emission of carbon dioxide has become the focus of attention of all countries in the world. As an important industry of the world economy and trade, the shipping industry has an unshirkable responsibility in energy saving and emission reduction and carbon emission reduction. Transport by sea has long been considered a relatively clean mode of transport compared to other modes of transport, such as air, road and rail. Although shipping accounted for only 2.33% of the total global carbon dioxide emissions in 2018, the annual carbon dioxide emissions were still as high as 828 million tons. There is still considerable pressure to cut carbon emissions by 30% by 2025 compared with 2008, as required by the International Maritime Organization (IMO). In the shipping industry, carbon dioxide emissions mainly come from the burning of fossil fuels, including light and heavy fuel oil, natural gas, etc. And the amount of carbon emissions and fuel consumption has a direct relationship. Reducing fuel consumption per unit volume and improving transportation efficiency are the core of ship energy conservation and emission reduction.

Experts and scholars at home and abroad have also conducted in-depth research and exploration in different fields to reduce carbon emissions in the shipping industry, providing some methods and suggestions for energy conservation and emission reduction of ships. Wu Xinxian [1] analyzed the application of new energy such as solar energy and wind energy as ship power in the ship field. Jonathan Childs [2]. Take measures to reduce operating costs and carbon emissions by installing electric propulsion systems and upgrading ship power plants

and streamlined thrusters. Xue Yingxia et al. [3] established a dual-objective programming model that minimizes the total cost and carbon emissions of container liner shipping line allocation, so as to achieve the purpose of energy saving and emission reduction for liner companies through shipping line allocation. Huang Zehui [4] analyzed the emission reduction measures of international shipping in three aspects: ship technology improvement, operation optimization and market mechanism. The market mechanism will affect the choice of emission reduction measures for ship technology improvement and operation optimization. In addition, by comparing the advantages and disadvantages of the carbon tax and the carbon trading mechanism under the market mechanism. Wu Anmin [5] et al. (2012) designed the waste heat utilization system of Marine diesel engine according to the waste heat utilization technology of Marine engine at home and abroad, and calculated the performance and economy of the system. Based on the relationship between engine power and fuel consumption, Li Sheng [6] (2011) calculated the fuel consumption and greenhouse gas emissions of ships at different sailing speeds, so as to reduce carbon emissions through speed reduction. Cariou P [7]. (2010) studied ships that reduce their sailing speed to achieve emission reduction, and studied whether deceleration sailing can become a long-term operation strategy for shipping companies by adjusting ship freight and fuel costs. The study showed that deceleration sailing strategy can be sustained only when the fuel price is 350 to 400 US dollars/ton. Yu Dongyan [8] used genetic algorithm to solve the problem, and discussed the impact on carbon emissions and business benefits under the condition of no Marine carbon tax and low, medium and high carbon tax rates.

Among them, most of the literature studies focus on the optimization of ship routes and use mathematical models to solve the problem to achieve the purpose of reducing carbon emissions. However, due to the complexity of the actual route situation and the uncertainty of various navigation factors, the ideal model is not of great reference value in the actual operation of ships. Some literatures study the application of electric energy, solar energy, wind energy and nuclear energy in the field of ships. However, due to the limitation of technical conditions, most of them are in the initial stage of experiments, so they are still unable to be applied to ships on a large scale and cannot replace the traditional internal combustion machine with fossil fuel in the short term. There are also some literatures that propose to reduce carbon emissions by reducing speed and power, but simply relying on speed reduction will directly affect the timeliness of ship transportation, thus affecting the competitiveness of shipping enterprises. Some literatures also put forward corresponding measures and suggestions for low carbon from the aspects of technical characteristics and operation management of ships. Most of them focus on qualitative analysis on how to reduce emissions in specific operation, and lack further analysis on how to achieve low carbon of ships.

In order to achieve the IMO 2025 and 2050 carbon emission targets, a systematic and comprehensive analysis of the current status, problems and challenges of ship carbon emissions is needed. Combined with the actual operation and management of the ship, the use of qualitative and quantitative analysis, through the comparison of experimental data, as close as possible to the actual operation of the ship, so as to put forward targeted solutions is the focus of this study.

## 2. Analysis of Carbon Emission Status of Shipping Industry

In 2018, the global total carbon emissions reached 37.129 billion tons, an increase of 2.7% over the same period last year and a historic high. The chart below shows the trend of global carbon emissions in recent years.

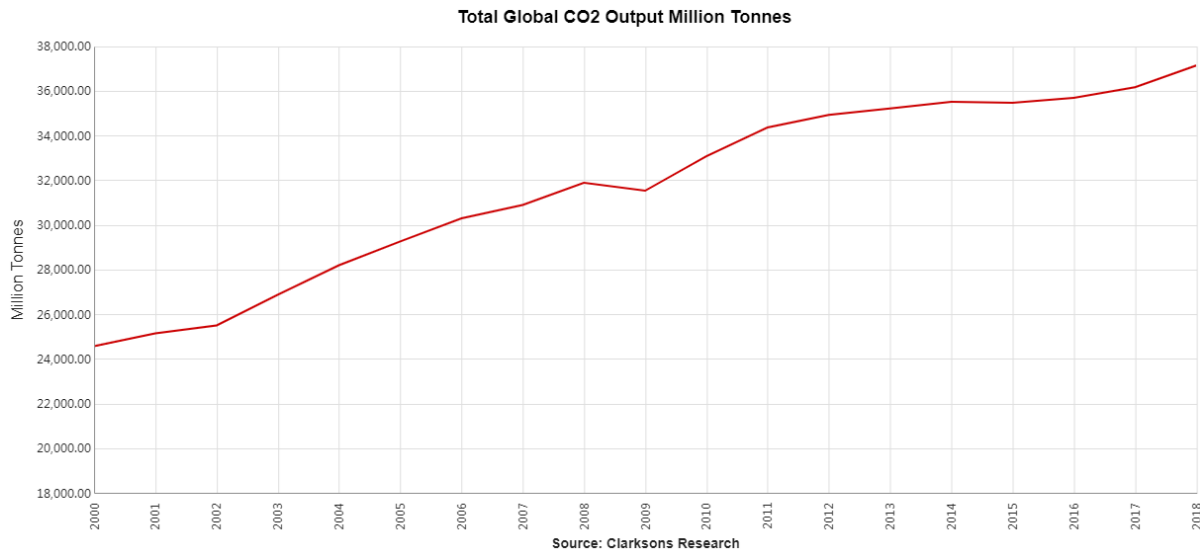


**Figure 1.** Trend chart of global total carbon emissions from 2000 to 2018 (source: Clarksons)

Compared with global carbon emissions, carbon dioxide emission reduction in the shipping industry has achieved certain results. The percentage of carbon emissions from ships in the global total carbon emissions showed a slow decreasing trend year by year. From 2008 to 2018, ships' CO<sub>2</sub> emission reduction reached 196 million tons, a year-on-year decrease of 19.1 percent. The global carbon dioxide emissions of shipping ships reached the peak of 1.024 billion tons in 2008 and fell considerably. However, in the past five years, with the gradual recovery of the shipping industry from the financial crisis and the continuous expansion of the fleet size, the decline of carbon dioxide emissions slowed down and even showed a slight increase in the future, leading to greater pressure on emission reduction. The following table shows the percentage of carbon emissions from ships in the total global carbon emissions and the trend chart of global carbon emissions from ships.

**Table 1.** The percentage of carbon emissions from ships in the total global carbon emissions in 2008-2018

| Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|------|------|------|------|------|------|------|------|------|------|------|------|
| %    | 3.21 | 3.21 | 2.83 | 2.68 | 2.4  | 2.29 | 2.25 | 2.28 | 2.32 | 2.30 | 2.23 |

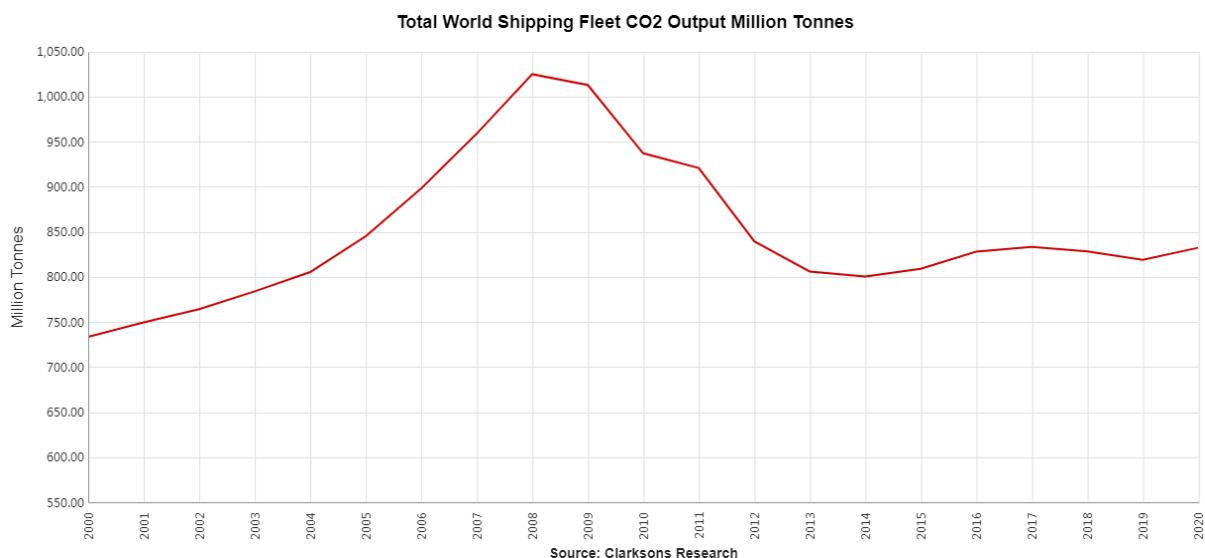


**Figure 2.** Global ship emissions trend chart 2000-2018 (source: Clarksons)

### 3. Regulations and Policies on Carbon Emissions in the Shipping Industry

#### 3.1. IMO Amendments on Pollution from Ships

On July 15, 2011, the 62nd meeting of the IMO Committee on Marine Environmental Protection passed Resolution MEPC.203 (62), the VI amendment of the Annex of the International Convention on the Prevention of Pollution from Ships (MARPOL 73/78), which determined the Energy Efficiency Design Index (EEDI) and Energy Efficiency Management Plan (SEEMP) for New Ships. Ship Energy Efficiency Management Plan, two Ship Energy Efficiency standards as mandatory global carbon reduction rules. It is the first global greenhouse gas reduction regime in the history of the shipping industry. EEDI is one of the indicators to measure the energy efficiency level of ship design and construction. It is the amount of fuel consumed by the same ship at a certain speed under the design maximum cargo capacity, and then the estimated CO<sub>2</sub> emissions of the ship are calculated. The larger the EEDI, the lower the energy utilization efficiency and the worse the economy of the ship. The EEDI standard is applicable to all ships with a gross tonnage of 400 and above and is implemented in the following stages based on the 2008 Reference line value:

**Table 2.** Table of phase targets for carbon dioxide reduction from 2013 to 2050

| Period                | 1         | 2         | 3         | 4         | 5     |
|-----------------------|-----------|-----------|-----------|-----------|-------|
| Time                  | 2013-2014 | 2015-2019 | 2020-2024 | 2024-2050 | 2050- |
| Reducing percentage % | 0         | 10        | 20        | 30        | >50   |

#### 3.2. EU CO<sub>2</sub> Monitoring, Reporting and Verification Regulations

In order to better monitor and reduce carbon dioxide emissions, to achieve the shipping industry emission reduction targets. On 28 April 2015, the European Parliament approved a new shipping regulation ("MRV" Monitoring, Reporting and Verification) on carbon dioxide emissions as part of its overall strategy to reduce greenhouse gas emissions by 2050. The regulation went into effect on July 1, 2015. From 31 August 2017, all ships entering, leaving and sailing in EU ports with a gross tonnage of more than 5,000 tonnes should have a CO<sub>2</sub> monitoring plan reviewed by a third party.

The plan must include: details of the shipping company's emission sources; Plan procedures for updating and monitoring navigation times and distances; Procedures for monitoring berthing time in ports and anchorages and monitoring fuel consumption; Including applicable monitoring methods; Monitoring tools and data management details and density calculation methods; Monitoring the emission rate of each fuel and monitoring the procedures for recording the cargo and passenger classes for each voyage will be carried out on a per-voyage basis and the data will be aggregated into the annual emissions report. The first monitoring report is required to be submitted on January 1, 2018 solstice on December 31, 2018. When monitoring is complete, data collected in accordance with the monitoring plan will require authentication by an approved third party. Once the certification process is successfully completed, the ship will be provided with a compliance document, which the ship should keep on board for inspection. Penalties for vessels without such documents include detention of the vessel and the issuance of an expulsion order banning the vessel from entering EU ports. The reporting period starts from January 1, 2018. Shipping companies are required to monitor and calculate the emissions of each ship that docks at EU ports on an annual basis and on the basis of the number of voyages to and from EU ports. Complete and submit the first monitoring report verified by the audit before April 30, 2019; Hold DOC until June 30, 2019. The formal entry into force of this rule establishes a framework for the monitoring, reporting and verification of greenhouse gas emission data for international shipping.

## 4. Measures to Reduce Emissions in the Shipping Industry

To meet the IMO's target of reducing carbon emissions by 30% by 2025 compared with 2008 levels, the global shipping industry will have to reduce emissions by 10% from the baseline of carbon equalization over the next five years. The pressure to cut emissions is still huge. In view of the urgent low-carbon emission reduction problems in the current shipbuilding industry, this paper puts forward corresponding solutions from the three stages of new building, operation and later operation.

### 4.1. Low Carbon Emission Reduction of Newly Built Ships

#### (1) Design of the ship

Hull optimization, reduce ship resistance; Reduce the air resistance of the ship's superstructure; Improved propeller design with front duct and propeller hub cap fins for improved propeller efficiency.

#### (2) Material selection

Shipbuilding needs to consume a lot of steel. Optimizing the loading structure of ships and using steels with higher fatigue strength can effectively reduce the dead weight of ships and reduce carbon emissions during ship construction and subsequent operation on the premise of meeting the requirements of total longitudinal bending resistance and structural strength of ships.

#### (3) Large-scale construction of ships

According to their own operating characteristics and in line with the company's development plan, shipping enterprises build large ships to achieve scale effect and low carbon ships. The scale effect is mainly reflected in the following two aspects: one is the scale effect of construction cost; Second, the scale effect of transportation cost and fuel consumption.

#### (4) Application of new electric jet engine and LNG fuel powered engine

Currently, the main electric jet engines on the market are MAN B&W ME-C and SULZER RT-FLEX. Through the highly intelligent electronic control system, the main engine can maintain good injection pressure and injection rate under different working conditions, and has the characteristics of good power performance, low fuel consumption and low carbon dioxide emission. At present, most newly built ships adopt these two Marine main engines to realize their economy and low emission. Using LNG as fuel engine function can effectively reduce fuel consumption rate and save operating costs, but also can improve the efficiency of the main engine, greatly reduce the EEOI value, reduce greenhouse gas emissions.

The conversion coefficient of carbon content and CO<sub>2</sub> content of different fuels is shown in Table 3. It can be seen that compared with traditional high-sulfur fuel, the CO<sub>2</sub> consumption per unit power of LNG fuel is reduced by 13%, which is one of the reasons why LNG is increasingly chosen as the main propulsion power for newly built ships.

**Table 3.** Conversion coefficient of fuel and CO<sub>2</sub>

| Fuel Oil type |                 | Carbon content | C <sub>F</sub> (t-CO <sub>2</sub> /t-fuel oil) |
|---------------|-----------------|----------------|------------------------------------------------|
| DO/MGO        | ISO8217 DMC-DMX | 0.875          | 3.20600                                        |
| LSFO          | ISO8217 DMA-RMD | 0.86           | 3.15104                                        |
| HFO           | ISO8217 RME-RMK | 0.85           | 3.11440                                        |
| LPG           | Propane/butane  | 0.819/0.827    | 3.00000                                        |
| LNG           | methane         | 0.75           | 2.75000                                        |

## 4.2. Carbon Emission Reduction in Ship Operation

The carbon emission control of ships in operation is the key direction of the text research, because the life cycle of general ships is about 20 years, and the age of most ships in the market is 5-10 years. Scientific management and planning of the above ships is the key to achieve the carbon emission target of 2025. The following analysis will be carried out from the technical level of mechanical equipment and operation management of ship operation.

### 3.2.1 Mechanical equipment carbon emission reduction management

The fuel consumption of auxiliary engine is directly related to the power load of the ship. In general studies, the fuel consumption of generator is regarded as a fixed value, and the fuel consumption of generator and boiler is less than that of main engine, which is easy to be ignored. There are few studies on this issue at home and abroad. In fact, through good operation management, scientific operation and reasonable distribution of generator load, can effectively reduce fuel consumption and carbon emissions.

(1) Generator is the core equipment to provide electric energy for ships. Its power source is formed from the combustion of prime mover. Ships usually have 3-4 generators, at least one of which needs to be operated 24 hours a day to power the ship's equipment (except for shore power and dock repair in some ports).

The carbon emission reduction of generators is mainly carried out from the following two aspects; (A) Reduce unnecessary load. Under the premise of meeting the normal operation of the ship, reduce the number of high-power equipment such as sea water pump and low-temperature cooling water pump. The investigation found that many ships still run two seawater and fresh water cooling water pumps at economic speed, resulting in a great waste of energy. (B) in a high power load condition, keep a generator to run as far as possible, the survey found many turbine management personnel on the generator load just close to 80% when parallel two generator running, sometimes, the situation will last the whole voyage, when in fact generator running at 85% load is feasible, the high load of fuel injection pump fuel injection pressure increased, atomization effect is better, more fuel-efficient equipment units. In order to avoid the power jump caused by the start of other high-power equipment, such as ballast pump, it is necessary for the engineer management to inform the bridge and seek the approval of the engine department before starting the ballast pump equipment. The engineer shall decide whether to start another generator according to the load condition at that time to ensure the safe operation of the ship.

The case takes a 9400TEU container ship operated by BS Company as an example. The ship is equipped with 4 generators, the model is Daihatu 8DC-32E, and the rated power is 3320KW. The fuel consumption rate of the generator under different loads is shown in the table.

**Table 4.** Fuel consumption of 8DC-32E generator under different loads

| Load %                | 0    | 25    | 40    | 50    | 75    | 80    | 100   |
|-----------------------|------|-------|-------|-------|-------|-------|-------|
| Time min              | 20   | 20    | 20    | 20    | 20    | 20    | 20    |
| Power KW              | 0    | 830   | 1330  | 1660  | 2490  | 2660  | 3320  |
| Fuel consumption kg/h | 62   | 211.9 | 296.5 | 345.6 | 497.0 | 530   | 658.7 |
| SFOC g/kwh            | ---- | 242.7 | 222.5 | 201.7 | 194.1 | 193.8 | 192.8 |

(Source: M ship actual load test)

The boiler is the equipment that provides steam heating for ships. Because most ships burn poor quality oil with high viscosity now, the fuel oil needs to be heated to meet the fluidity and combustion atomization requirements of barge transport. When the ship docks at the port or at anchor, steam heating is also needed to warm the cylinder liner water. When docking at the

port, turn off the heating steam of the fuel oil tank and bypass the seawater cooling water flow to meet the basic requirements of cooling of the generator, reduce the combustion load of the boiler and reduce fuel consumption. Such as the use of generator prime mover combustion to eliminate the high temperature waste gas, the use of waste gas recycling heating to produce steam, thereby reducing the boiler to port fuel consumption.

### 3.2.2 Optimize ship operation management to reduce carbon emissions

#### (1) Optimal design of shipping routes

The optimal design of shipping routes mainly includes two aspects. One is to arrange ships and optimize shipping routes according to the port of call and cargo source conditions of ships, with the goal of maximizing operating benefits and minimizing carbon emissions. Second, after the overall route is established, according to the actual situation between ports, such as the time of docking, anchoring time, water diversion and other details, the ship speed should be adjusted in a targeted and timely manner to achieve the lowest fuel consumption.

#### (2) Optimize the amount of ballast water and rationally add fuel to reduce emissions

Optimize the stowage mode to reduce the use of ballast water as much as possible; The total volume of the ballast tanks of ship M is 31881m<sup>3</sup>. In daily operation, the ship has 4 tanks for pressurized water carrying, which are 1 port tank (1P), 1 starboard tank (1S), 5 port tank (5P) and 5 starboard tank (5S) respectively. Among them, the port side (1P) and starboard side (1S) of Hatch 1 are 90% of the hold capacity. In the experiment, under the condition of reasonable stowing to meet the basic safety of the ship, only 5P and 5S anti-balance special tanks should be kept to maintain certain ballast to meet the requirements of the ship's arrival unloading. At the same time, due to the limited pumping capacity of ballast pump, there is still some sea water remaining in other empty tanks without ballast, which accounts for about 5% of the tank capacity. Special vacuum jet pump can be used to clear the remaining ballast water in other tanks.

### 4.3. Carbon Emission Reduction in the Later Period of Ship Operation

After the ship enters the later period of operation, due to the aging of machinery and equipment, its dynamic performance and thermal efficiency become worse, fuel consumption increases, and carbon emission intensifies, resulting in the economic decline of operation. At this time, aging ships should be dismantled to eliminate backward production capacity to reduce carbon emissions. Due to the shipping industry is a large upfront investment yield and relatively low industry, relying on shipping enterprise bigger challenges facing backward production capacity, all round the world for nearly a decade of ship dismantling, dismantling volume in 2012 reached 592.2 million tons after peak presents downward trend year by year, which requires governments to give corresponding subsidies and policy support to arouse the enthusiasm of enterprises to reduce emissions out inefficient vessels, and financial sector give corresponding bank loans and financial support for shipping enterprises is very important for the shipping update. The financing of energy saving and environmental protection ships will bring opportunities and challenges to the development of Marine financing organizations. In June 2019, 11 large ship finance banks signed the Poseidon Code, which aims to encourage financing of low-carbon ships, promote decarbonization of Marine ships, and reduce refinancing support for older ships. It will contribute to the realization of the IMO 2025 and 2050 carbon dioxide emission reduction targets. The tonnage of ships dismantled over the years is shown as follows:

**Table 5.** Global tonnage table of ships dismantled 2009-2018 (unit: million tons)

| Year | Oil tanker | Bulk carrier | Container ship | Others | Total |
|------|------------|--------------|----------------|--------|-------|
| 2009 | 8.56       | 10.61        | 6.03           | 8.86   | 34.06 |
| 2010 | 13.18      | 6.57         | 1.98           | 7.1    | 28.83 |
| 2011 | 9.92       | 23.28        | 1.25           | 9.35   | 43.80 |
| 2012 | 11.96      | 33.41        | 4.97           | 8.88   | 59.22 |
| 2013 | 11.08      | 23.19        | 6.31           | 7.05   | 47.63 |
| 2014 | 7.79       | 16.39        | 5.34           | 4.58   | 34.10 |
| 2015 | 2.54       | 30.7         | 2.86           | 3.32   | 39.42 |
| 2016 | 2.56       | 29.33        | 8.76           | 4.26   | 44.91 |
| 2017 | 11.20      | 14.66        | 5.35           | 4.45   | 35.66 |
| 2018 | 20.46      | 4.42         | 1.59           | 4.51   | 30.98 |

## 5. Summarizes

This article study on the three period of shipping carbon emissions including the early period of the operation, operation of the ship and in the operation of the later period , with BS company ships as an example, consider the operation of the ship generator and optimal management of ballast water to reduce fuel oil consumption, by the corresponding experimental comparison and to certify that the above method can effectively reduce carbon emissions and help shipping 2025 carbon emissions goals on schedule; At the same time to other shipping companies to reduce carbon emissions to provide a useful reference and reference. The shortcoming of this paper is that it does not involve how to optimize and reduce carbon emissions in ship dismantling operation, which will be the focus of future research.

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