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Modeling and Analysis of Comprehensive Benefit Evaluation of Electric Ships based on Life Cycle Analysis

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Abstract

In order to reduce pollution and reduce global greenhouse gas emissions, the electrification of the shipping industry has gradually attracted people's attention. Although electric vehicles have the advantages of energy saving, emission reduction, and low noise, their environmental, economic and social benefits still need to be improved. This article starts from the comprehensive benefits of electric vehicles, use full life cycle analysis to analyze it in detail and finally got the result. As the energy consumption and emissions of electric ships still exist, the cost of batteries is still too high at this stage, priority can be given to the development of inland river, medium and short distance electric vehicles transportation, and then gradually develop ocean shipping.

Keywords

Shipping; Comprehensive Benefits; Full Life Cycle Analysis (LCA); Electric Vehicle.

1. Introduction

As an important link in the field of transportation, shipping is a necessary link for more than 90% of the global cargo transportation. In recent years, the annual growth rate of global shipping trade has exceeded 3%, reaching a total of 10.837 billion tons [1]. With the introduction of a series of national strategies such as the "Marine Power", "One Belt, One Road" and "Yangtze River Economic Belt" construction, it has also brought new opportunities for the further development of my country's shipping industry. However, the rapid development of shipping will also face some problems and challenges, such as energy consumption and greenhouse gas emissions. According to a recent study, CO2 emissions from shipping account for about 3.3% of global man-made greenhouse gas emissions. If no relevant restrictive measures are taken, the total CO2 emissions of the shipping industry will account for 12%-18% of the total allowable CO2 emissions worldwide by 2050. At the same time, with the continuous improvement of environmental protection awareness, people have also proposed "cleaner oceans" and decarbonization, and the electrification of maritime transportation has also been paid more and more attention.

However, at present, more than 90% of my country's waterborne ships still use diesel-powered propulsion systems, which have problems such as high fuel costs, high noise, and emission pollution. For these problems, life cycle analysis or other analytical methods are generally used to explore the decarbonization potential of maritime transportation or shipping. The early development of life cycle analysis methods mainly focused on energy production systems, such as nuclear power, coal, and solar photovoltaic power generation [2]. Traditional research focuses on researching technologies and operational measures to reduce carbon emissions, such as [3], but few have adopted these methods to explore the development potential of electric ships.

This article considers that compared to fuel-fueled ships, electric ships have the advantages of low pollution, low noise, low vibration, high technical added value, easy integration and standardization,

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low operating costs, and high safety and reliability. However, they also have shorter battery life, Issues such as battery life require in-depth analysis. At the same time, my country's shipbuilding industry is at a critical stage of accelerating transformation and upgrading and moving towards high-quality development. While strengthening engineering research and development and application, it is more necessary to improve relevant technical standards and management policies. Provide support and guarantee to promote the "electricity" of ships.

2. Methodology

2.1 Life cycle analysis

The design life of a ship is generally 30 years, and its life cycle covers the design, construction (including the procurement of raw materials), shipping (port operations, offshore operations), repairs, and dismantling processes. This method divides the entire life cycle of an electric ship into a ship chain and a fuel chain, as shown in Figure 1. The ship chain is mainly divided into the hull subsystem and the electromechanical subsystem. The electromechanical subsystem mainly includes the power system, special outfitting, and electromechanical equipment. Each subsystem of the ship can be divided into three stages, namely the production stage, the use stage and the scrap processing stage. In addition, the fuel chain includes the production and use of fuel.

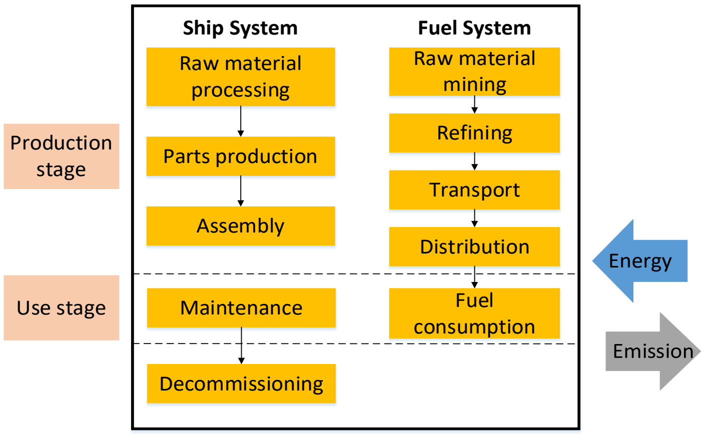

Figure 1. Full life cycle frame work of electric ships

2.2 Life cycle energy consumption analysis

In the process of ship construction, not only the energy consumption of the main engine, auxiliary machinery, propulsion mechanism and so on, such as electric ships, but also the energy consumption of the power battery manufacturing process need to be considered.

The main sources of energy consumption during ship operation are the main engine, auxiliary engines and boilers. Among them, the power of the main engine is related to the ship's speed, deadweight, wind and waves, and external surface corrosion. The most important thing is the speed. The power of auxiliary engines and boilers is related to the ship's sailing mode. Assuming that a ship has nt voyages a year, refer to related literature [4] to get the annual fuel consumption formula as follows:

$$\boldsymbol{F_k} = \sum_{i=1}^{nt}\sum_{l=1}^{m}\left(P_{ilk}^{main} \times SFOC_{lk}^{main} \times T_{ilk}^{main}\right) + \sum_{i=1}^{nt}\sum_{j}^{m}\left(P_{ijk}^{aux} \times SFOC_{k}^{aux} \times T_{ijk}^{aux} + P_{ijk}^{boiler} \times SFOC_{k}^{boiler} \times T_{ijk}^{boiler}\right) \tag{1}$$

where nt refers to there are a total of nt voyages between the two ports throughout the year; i refers to i voyage; j refers to Sailing mode; k refers to fuel type; 1 refers to the first flight segment

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of a voyage, the host load factor of the same flight segment remains unchanged; m refers to the total number of flight segments included in a voyage; F_k refers to the fuel consumption of the ship's fuel k in a year; $F_{\boldsymbol{ilk}}^{main}$ refers to main engine fuel consumption for voyage i, segment 1, fuel k; $F_{\boldsymbol{ijk}}^{boiler}$ refers to the boiler fuel consumption of voyage i, sailing mode j, and fuel oil k.

Refer to [5], calculate the host power as

$$P_{main} = P_{ref} \times \left(\frac{V_{act}}{V_{design}}\right)^3 \times \left(\frac{t_t}{t_{ref}}\right)^{\left(\frac{2}{3}\right)} \times f_w \times f_f \tag{2}$$

where $\mathrm{P_{ref}}$ refers to host rated power; $\mathrm{V_{design}}$ refers to maximum speed; t_t refers to actual draught; $\mathrm{t_{ref}}$ refers to rated draft; f_{w} refers to weather influence factor; f_f refers to ship surface influence coefficient; $\mathrm{V_{act}}$ refers to ship speed.

In addition, the life-cycle emission energy consumption of the ship operation subsystem includes not only the energy directly consumed by the operation of the ship, but also the energy consumed during the energy mining and production process. For fossil fuels such as marine diesel, it mainly includes the extraction and processing of raw materials and the transportation of fuel. For electricity, it includes the mining, processing, transportation and power generation process of raw materials for power generation. The calculation formula for the total energy consumption of fuel/electricity acquisition is shown in the following formula:

$$E_{WTT} = \sum E_i(1 + E_{p,i} + K \times E_{e,i}) \tag{3}$$

where E_{WTT} refers to total energy consumption per unit of energy product; E_i refers to energy consumption of fuel i per unit of energy product produced; $E_{p,i}$ refers to energy consumption in the production stage of fuel i; $E_{e,i}$ refers to energy consumption in the extraction stage of fuel i; K refers to loss factor.

In the process of ship scrapping, the main consideration is the energy consumption in the hull cutting and power production process. Material recovery is to put a large amount of waste steel produced during the dismantling of the ship into new steel through a recycling process.

2.3 Life cycle emission analysis

In the process of ship construction, in addition to considering the emissions of the same parts of the main engine, auxiliary engines and traditional ships, data from the ANL Greet model database can also be used to analyze the power batteries of electric ships.

During the operation of the ship, the main equipment on the ship directly generates emissions due to fuel combustion. The actual emission factor of the ship is related to the baseline emission factor of the ship, engine production year, engine type, engine speed, fuel type and sulfur content, and engine load. The formula is as follows:

$$EF = EF_{baseline} \times FCF \times LLA \tag{4}$$

where $EF_{baseline}$ refers to baseline emission factor; FCF refers to fuel correction factor; LLA refers to host low load correction factor.

Air pollutant emissions can be calculated based on energy consumption and air pollutant emission factors:

$$E_p = \sum_{k=1}^{nf} \left(F_k \times EF_{kp} \times LLA\right) \tag{5}$$

where k refers to k fuel; nf refers to total number of fuel types; p refers to types of air pollutants; $\boldsymbol{EF_{kp}}$ refers to emission factors of fuel k and air pollutants p. In addition, emissions during the entire life cycle of a ship's operation also include emissions from the energy mining and production process.

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In the process of ship scrapping, both the scrapping and recycling of the hull and the recycling of related equipment inside the hull will generate emissions. At the same time, it is also necessary to consider the recycling of electric ship power system batteries.

2.4 Net present value

A cost-benefit analysis (CBA) method is proposed to evaluate life cycle costs and the transportation costs of electric ships and traditional ships. CBA is usually done by discounting future benefits and costs relative to the current value, also known as the net present value (NPV) method. The CBA method has been used in conjunction with LCA research, as seen in, it can help decision makers better understand the meaning of decision-making by quantifying the consequences of various situations.

In the life cycle system of electric ships discussed in this article, life cycle costs include investment costs, operating costs, fuel (electricity) costs, and decommissioning costs. According to the definition, the total discounted cost (TDC) [6] of the entire electric vessel can be expressed as:

$$TDC = \sum_{t=0,1,2,\ldots} (INV_t + O\&M_t + FUEL_t + DECOMM_t - RESID_t) \times (1+r)^{-t} \tag{6}$$

where TDC refers to discounted lifetime cost; INV_t refers to the initial investment cost of ship construction; $O\&M_t$ refers to operation and maintenance costs (except fuel and electricity); $FUEL_t$ refers to fuel and electricity costs during transportation; $DECOMM_t$ refers to the cost of decommissioning the ship; $RESID_t$ refers to recyclable scrap value at the end of the full life at the end oft; r refers to discount rate.

3. Case

3.1 Ship details

This section selects three ship types: excursion ship, ferry ship and inland container ship as examples. Based on the basic ship type, it is assumed that battery-powered ships of the same ship type, same route, and same mileage are assumed. Investigate and sort out relevant data. Among them, the cruise ship's route is Shanghai World Expo U-turn Area, with 330 days of voyage per year, 418 voyages per year, annual voyage mileage of 9196 kilometers, and average speed of each voyage is 7.2 nautical miles per hour. The ferry route is Zhenjiang-Yangzhou, the annual number of voyages is 22,935, the annual voyage mileage is 38,989 kilometers, the average daily voyage mileage is 63.7 kilometers. The inland river container ship route is Suzhou-Yangshan Port, the annual number of voyages is 90 times. The annual mileage is 36000km, and the speed is 10 nautical miles per hour.

3.2 Environmental benefit analysis

According to detailed ship information and related assumptions, the energy consumption and emissions of the two power system ships in the construction phase, the use phase and the scrap phase are calculated respectively. According to the actual situation, assuming that the life of the ship is generally 30 years and the life of the battery is 7.5 years, the battery needs to be replaced 3 times during the life of the ship. For a clearer comparison, the energy consumption and emissions per kilometer are used as the unit to calculate the unit energy consumption and emissions of the different power systems of the three ship types. Figure 2 is a detailed comparison:

In the energy consumption part, the difference between the two power system ships of the inland container ship type is only 1773.8MJ/km, and the difference between the two power system ships of the ferry ship type is the largest, 18333.4MJ/km, so the passenger ferry can use diesel and the effect of changing the power system to the power system is even more effective, while the effect of the cargo ship is not very obvious. In the emission part, the difference between the two power system ships of the inland container ship type is only 202.6kg/km, and the difference between the two power system ships of the ferry ship type is the largest, 2059.1kg/k. The detailed calculation results are shown in Table 1 and Table 2 below. In summary, due to the special passenger and transportation conditions of car-passenger ferries, the effect is more obvious after the replacement of the power

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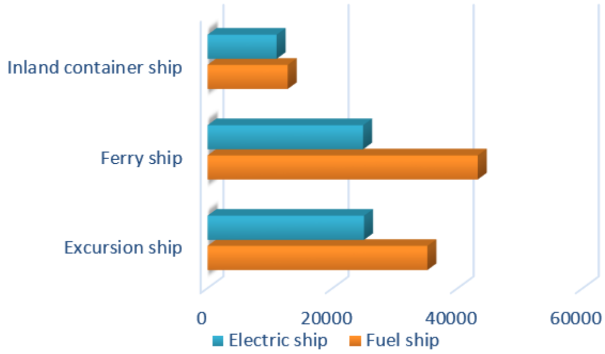
system, which also shows that electric ships can give priority to the development of small, inland river basin passenger ferries.



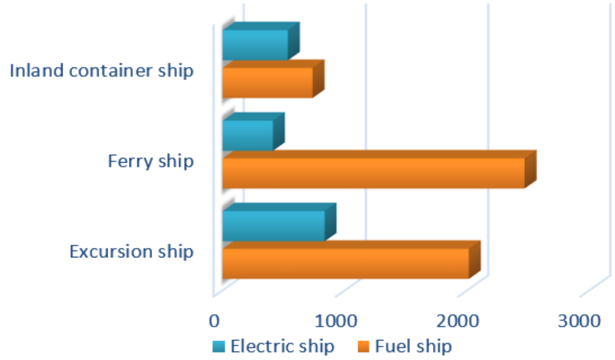


Figure 2. Comparison of unit energy consumption (left) and emissions (right)

Table 1. Comparison of unit energy consumption of ships (MJ/km)

	Excursion ship	Ferry ship	Inland container ship
Electric ship	25006.3	24862.3	11044.2
Fuel ship	35144.8	43195.7	12818

Table 2. Comparison of unit energy consumption of ships (kg/km)

	Excursion ship	Ferry ship	Inland container ship
Electric ship	834.1	411	532.9
Fuel ship	2014.2	2470.1	735.5

The unit energy consumption and unit emissions of electric ships are better than those of fuel oil ships. Although electric ships are not really "zero emissions", they will generate certain energy consumption and energy during the manufacturing stage of the battery and the power required during production and sailing emission. However, after the use of electric propulsion, the ship's power system has been simplified, which reduces the vibration and noise of the ship during operation or idling, and improves the comfort of the crew and passengers. Therefore, electric ships use a large number of clean energy sources to promote green and low-carbon energy. They can completely eliminate or use less high-carbon energy sources, and effectively reduce the use of diesel engines. At the same time, they can obtain environmental protection advantages of low noise and no smoke, which is beneficial to optimize the ship environment and also it is conducive to protecting the ecological environment of water bodies and has good social, ecological and economic benefits.

3.3 Economic Benefit Analysis

Combining the previous relevant information, the discount rate is 7% to calculate the comparison of the annual cost in the life cycle of the two types of ships, and to judge the pros and cons of the choice of ship type. According to the specific situation, this study assumes that the fuel price of fuel-fueled ships is 7 yuan/KG, and the electricity price of electric ships is 1.1 yuan/kWh. Similarly, this part takes the service life of the ship as 30 years and the service life of the battery as 7.5 years. The battery needs to be replaced three times during the life cycle. Combining the calculation of the above part, the following figure 3:

The cost of the battery-powered ships of the three ship types is higher, especially the cost of battery replacement is more obvious, but with the economic development and continuous improvement of technology, the cost of the battery will be greatly reduced, and the economic benefits of electric ships will also increase. The more obvious, especially the ship type of passenger ferry.

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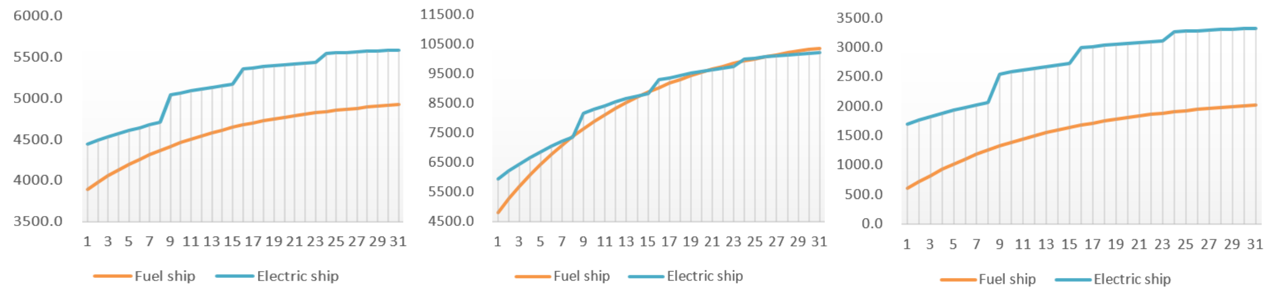

Figure 3. Comparison of annual costs

4. Conclusion

With the increasing awareness of environmental protection, the advantages of battery-powered ships for energy saving, emission reduction and environmental protection are becoming more attractive. However, the current electric ships are still limited by their high cost, troublesome power battery charging and endurance. Due to the limited time and insufficient supporting facilities, considering the application prospects of electric boats, its development can be carried out in stages:

First, the development of short- and medium-distance transportation, small and medium-sized inland waterway transportation. Since electric ships are still limited by the troublesome power battery charging, limited battery life, insufficient supporting facilities and so on. Long-distance navigation and mass transportation are still subject to certain restrictions, so the current priority can be given to the development of short- and medium-distance transportation, medium and small-scale inland waterway. In this regard, electric ships have a very broad prospects for development. Because all the power of electric ships comes from batteries, they have higher requirements for corresponding supporting facilities such as charging piles. In addition, the batteries used on electric ships are very to a large extent, it is restricted by the load capacity of the ship, so the volume and weight requirements of the battery are also stricter. Therefore, under the constraints of the current situation, the use of electric ships can be promoted to give priority to the development of short- and medium-distance transportation, inland navigation for small and medium-sized transportation, and official ships.

Secondly, after the battery technology and supporting facilities are gradually improved, coastal and ocean transportation for long-distance voyages and large-volume cargo transportation will be developed. With the development of economy and the continuous improvement of technological maturity, the use of electric ships can gradually develop from inland water transportation to coastal and ocean transportation.

References

[1] Horvath, S., Fasihi, M., Breyer, C.. Techno-economic analysis of a decarbonized shipping sector: Technology suggestions for a fleet in 2030 and 2040. Energy conversion and management. Vol. 164(2018), p.230-241.

[2] Nian V, Chou SK, Su B, Bauly J. Life cycle analysis on carbon emissions from power generation – the nuclear energy example. Applied Energy. Vol.118 (2014), p.68–82.

[3] Nian V, Liu Y, Zhong S. Life cycle cost-benefit analysis of offshore wind energy under the climatic conditions in Southeast Asia – Setting the bottom-line for deployment. Applied Energy. Vol.1003 (2019) No.14, p.233-234.

[4] Byongug Jeong, Hyeonmin Jeon, Seongwan Kim, Jongsu Kim, Peilin Zhou. Evaluation of the Lifecycle Environmental Benefits of Full Battery Powered Ships: Comparative Analysis of Marine Diesel and Electricity [J]. Journal of Marine Science and Engineering. Vol.8 (2020) No.8.

[5] Perčić Maja, Vladimir Nikola, Fan Ailong. Life-cycle cost assessment of alternative marine fuels to reduce the carbon footprint in short-sea shipping: A case study of Croatia. Applied Energy. Vol.279 (2020).

[6] Maja Perčić, Ivica Ančić, Nikola Vladimir. Life-cycle cost assessments of different power system configurations to reduce the carbon footprint in the Croatian short-sea shipping sector. Renewable and Sustainable Energy Reviews. Vol.131 (2020).