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Study on the Development Path of Port Low-carbon Technology -- Taking Shanghai Port as an Example

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Abstract

The green development is the only way for future ports, and the application of low-carbon technology is an essential means for ports to achieve green development. This study first analyzes the sources of carbon emissions in ports, then lists the latest low-carbon technologies in ports, and summarizes the practices of Shanghai Port in applying low-carbon technologies. Finally, it proposes a development path for promoting low-carbon technologies in ports from the perspectives including adopting clean low-carbon energy system, optimizing collection and distribution system, improving equipment electrification, and developing digital intelligent technology.

Keywords

Ports; Low-carbon Technology; Shanghai Port; Green Energy.

1. Introduction

Reducing greenhouse gas emissions has become a global consensus. At the 2015 United Nations Climate Change Conference in Paris, nearly 200 countries and regions reached a historic agreement to reduce global greenhouse gas emissions (Yang et al, 2018), which specified that the temperature control goal is to "control the increase in global average temperature within 2 °C compared to the pre-industrial period, and strive to limit the temperature increase to within 1.5 °C". On November 1-12, 2021, the 26th Conference of the Parties (COP26) of the United Nations Framework Convention on Climate Change (UNFCCC) was held in Glasgow, United Kingdom. This meeting signed the Glasgow Climate Convention, requiring governments to take prompt action and providing for carbon trading markets, transparency, and a common time frame (Brandt and Svendsen, 2022).

International trade transportation is one of the important sources of carbon emissions, and maritime logistics accounts for over 85% of international trade goods transportation, all of which are transported through seaports. Between the year 2000 and 2015, the energy demand for international shipping, including seaports, increased by an average of 1.6% per year (UNCTAD, 2016), which has brought certain obstacle for global carbon emission reducing. The port industry, accounting for 3% of global greenhouse gas emissions (Misra, et al, 2016), is a key monitoring target for carbon reduction by governments around the world. Faced with the pressure of environmental protection, governments are striving to regulate the operation of port areas. For example, the European Union (EU) and North American ports have implemented emission control areas (ECAs) policies to reduce carbon emissions near ports (Chang et al, 2018). How to reduce port carbon emissions has become an urgent and important issue for governments around the world (Iris and Lam, 2019), and the use of low-carbon technology is one of the important means to reduce port carbon emissions (Woo et al,2018).

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2. Literature Survey

The research on low-carbon technologies in ports mainly includes port carbon emission calculation, port energy substitution, port equipment, technologies in lighting, and energy management. There are some literatures that made profound investigations in this field.

2.1. Port Carbon Emission Calculation

Some researchers paid special attention to the calculation of port carbon emission. Among others, Hall (2010) supported the ports to use shore power in order to reduce the emission of polluting gas from port, thus decreasing CO2 by 24.5% and NOx by 91.6%. From another angle, Cho (2014) held an empirical study on carbon emissions of a single container in port logistics, which could be divided as transportation within and outside the port. Lam & Eddy (2012) constructed a calculation model of carbon emission from port buildings, and took three cases of ports from North America, Europe, and Asia respectively as instances. Jiang et al. (2012) calculated the carbon emission from port multimodal transportation such as roadesea, railwayesea and riveresea. Alamoush et al. (2022) analyzed the method of government to calculate the port carbon emission, while Wang & Li (2023)'s analysis focused on the calculation method that the ports are using.

2.2. Port Carbon Emission Calculation

There still some researchers who studied the topic of port energy substitution. For example, Edward et al. (2015) discussed the application of cold-ironing in ports, and suggested that renewable energy, liquefied natural gas, and other power sources can replace traditional electricity, thereby reducing port carbon emissions. Kenan et al. (2016) considered wielding shore power in port energy and found that shore power has an price advantage of 0.19 USD/kWh over traditional electric power. Coppola et al. (2016) paid attention to the use of smart electrical interfaces in port intelligent devices, which can effectively improve the synergy of low-carbon intelligent devices in ports, thus improving the efficiency of port equipment work and reducing carbon emissions from equipment.

2.3. Port Equipment

Port equipment is an important source of port carbon emissions, and how to reduce port equipment carbon emissions has become one of the key focuses of scholars. Zhao et al. (2014)[carried out a research about the energy recycle of Quay Cranes（QC）and Ship-to-Shore cranes in ports, since QC can recover a huge amount of energy during crane descent which can be stored for future use. Peng et al. (2016) compared the emissions from two kinds of RTG (Rubber-Tired Gantry crane): E-RTG and diesel RTG, and showed that E-RTG can not only reduce energy costs by 86.60%, but also reduce greenhouse gas emissions by 67%. Tan & Yap (2017) gave a design to fix flywheel installment to TRG, thus reducing the energy consuming of RTG by 30% as well as prolonging the age of engine. The influence of e-mobility on the automation efficiency and carbon emissions of AGV and other equipment was analyzed by Bechtsis et al. (2017) and their results proved that battery-powered AGV offers higher efficiency, reliability and safety. Parreno-Torres et al. (2022) used the beam search algorithm to solve the optimization of yard crane's premarshalling problem and obviously reduced the carbon emission from yard crane. Olgay (2023) led a study concerning vehicle carbon emission optimization of Ambarlı container port in Turkiye and indicated that replacing vehicles with green energy can effectively reduce carbon emissions.

2.4. Technologies in Lighting

Lighting consumes roughly 3–5% of total energy in ports. Rijsenbri & Wieschemann (2011) believed that ports should optimize their lighting levels and armatures to reduce energy

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consuming. Duin et al. (2017) calculated the energy-saving effect of using LED lights instead of high-pressure sodium lamps in ports. Under 11 hours of lighting demand, compared to high-pressure sodium lamps, LED lights can save 922 MWh per year. Nikolaos et al. (2021) proposed a novel replicable typology of smart-controlling the outdoor lighting infrastructures which can reduce the lighting energy consumption in ports by 56.8%.

2.5. Energy Management

Lynham et al. (2016) thought that real-time monitoring of the energy consumption can improve the level of port energy management and provide assistance in selecting appropriate energy-saving technologies. E. g., Port of Koper used real-time monitoring for yard operations energy consumption detection, achieving 281 MWh of electricity savings and reducing 311 tons of CO2 emissions in 2013 (Tran, 2012). Parise et al. (2016) discussed the implement of Combined Heat and Power in port energy substitution. Na et al. (2017) performed a comparison between carbon emissions of LNG-based terminal tractors and tractors using traditional energy, showing that LNG-based terminal tractors could reduce carbon emission by 16% and nearly without NOx emission. Emmanouil et al. (2022) conducted a simulations on the negative energy consumption of port vessel docking using HOMER PRO and held that the technology of Levelised Cost of Energy can reduce carbon emission by 51.8%. Flavio et al. (2022) deployed a method called hybrid renewable energy systems to calculate carbon emission of Ghana's Takoradi port and deemed that Photovoltaic /wind/battery/natural gas is the best energy choice of this port. Zhang et al. (2023) tried to find optimization of the integrated energy systems considering multi-energy collaboration in carbon-free hydrogen ports.

3. Sources of Carbon Emissions from the Ports

The sources of greenhouse gas emissions from ports can be divided into two categories. One is within the port area, and the other is outside the port area. Below, we will analyze these two types separately.

3.1. Sources of Carbon Emissions within the Port Area

The main source of carbon emissions generated by port production operations, office work and life mainly originates from energy consumption such as electricity, fuel, liquefied natural gas, etc. The specific sources consist of: (1) Indirect carbon emissions from electricity. The electricity in the port area is mainly used for port loading and unloading equipment facilities, refrigerated container areas, port lighting, living and office work, etc.; (2) Fuel carbon emissions. Port fuel is mainly used for port vessels, loading and unloading machinery, transportation vehicles, office vehicles, etc. The reduction of carbon emissions from fuel powered machinery is mainly achieved through the substitution of clean energy. Newly purchased machinery and vehicles prioritize the use of clean energy. Currently, there are plans to improve fuel powered machinery such as "oil to electricity" or "oil to hydrogen", reducing fuel consumption and ultimately achieving zero carbon emissions; (3) LNG carbon emissions. LNG in the port area is mainly used for towing vehicles in the port area. As a type of fossil fuel, LNG still generates carbon emissions during use.

3.2. Sources of Carbon Emissions Outside the Port Area

The main sources of carbon emissions outside the port area are generated by berthing ships, inbound trains, inbound trucks, and external construction vehicles and facilities. The specific sources are: (1) Carbon emissions from berthing ships. As a port for ship transportation and loading and unloading, a large amount of carbon dioxide is emitted due to fuel consumption during ship docking and loading and unloading. (2) Carbon emissions from freight transport vehicles. The vigorous development of the "transit to rail" and container sea rail intermodal

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transportation in some ports has led to a significant reduction in inbound diesel trucks, an increase in the number and frequency of inbound train locomotives, and a certain amount of carbon emissions. At the same time, container road transportation accounts for a relatively high proportion of road transportation, and the total number of daily heavy trucks entering and leaving the port area is still high. The main fuel for heavy trucks is fossil fuels such as diesel and LNG, and their process of entering the port generates a large amount of carbon emissions.

4. Types of Low-carbon Technology in Port

There are three main types of low-carbon technologies in ports, namely new energy technology substitution, facility transformation technology, and intelligent technology. The substitution of new energy technologies mainly includes green energy (such as photovoltaic power generation, wind power, solar energy development, tidal energy, wave energy), new fuel applications (such as liquefied natural gas, biomass fuel, hydrogen and ammonia applications), and oil and gas recovery system transformation. The transformation technology of facilities mainly includes electrification transformation of mobile machinery and tugboats, LED lighting fixtures, introduction of intelligent lighting control systems, electrified logistics equipment, port ship shore power system, and cold chain transportation. The intelligent technology mainly includes energy intelligent control platforms. These technologies belonging to three types are shown in Table 1:

Table 1. Types of low-carbon technology in ports

Types	Main technologies
Substitution of new energy technologies	photovoltaic power generation, wind power, solar energy development, tidal energy, wave energy
	liquefied natural gas, biomass fuel, hydrogen and ammonia applications
	oil and gas recovery system transformation
Transformation technology of facilities	electrification transformation of mobile machinery and tugboats
	LED lighting fixtures, introduction of intelligent lighting control systems
	electrified logistics equipment
	port ship shore power system
	cold chain transportation
Intelligent technology	energy intelligent control platforms

5. The Implementation of Low-carbon Technology in Shanghai Port

Located in the middle of the coastline of Chinese Mainland and at the mouth of the Yangtze River, Shanghai Port is accessible to many provinces in China and is one of the most important foreign trade portals in China. Shanghai Port was the earliest port in China to explore the path of green port development. In early 2005, in order to alleviate the contradiction between port development and environmental protection, Shanghai Port took the lead in integrating the concept of green and low-carbon development into the strategic planning of enterprise development. In 2013, the construction of green ports was officially launched, and at that time, the focus of development was mainly on green technology innovation projects. In 2015, Shanghai International Port Group (SIPG) formulated the "Special Plan for Building Green, Circular, and Low Carbon Ports and for Energy Conservation and Emission Reduction (2015-2020)" and the "Three Year Action Plan for Shanghai Port Group to Create Green Ports (2015-

2017)", covering a total of 29 key support projects from 7 aspects, including the application of LNG terminal tractors, RTG energy-saving and emission reduction renovation, LED green lighting, port ship shore based power supply technology, and tugboat energy-saving technology, etc.. In December 2014, Shanghai Port launched the Yangshan Phase IV Automation Terminal Project, which applied advanced technologies such as remote control bridge cranes, fully automatic track cranes, fully electric drive AGVs, intelligent scheduling systems, second-generation port ship shore based power supply, energy-saving new light sources, solar assisted heating and so on. The project took three years to complete and was officially put into operation in December 2017. Through a series of energy-saving and emission reduction measures implemented at the port, Shanghai Port has achieved good development in the creation of green ports. In recent years, Shanghai Port has implemented measures in the development process of creating green ports, including environmental management system, green port development plan, application of energy-saving and emission reduction technology, and automated port construction.

5.1. Building an Environmental Management System for Shanghai Port

As a public terminal operator of Shanghai Port, SIPG promotes the development of its energy management system through the establishment of regulations and scientific management, and integrates environmental management into its daily business management processes. In terms of energy management, SIPG includes energy consumption in its annual budget goals besides constructing a strict energy management assessment mechanism. It has established a budget leadership group and working group to regularly evaluate budget implementation and ensure the achievement of budget goals. Since the comprehensive implementation of centralized procurement and supply of oil products by SIPG in 2013, in recent years, it has continuously strengthened the centralized control of oil products and the informatization of oil usage management, achieving real-time control of major loading and unloading equipment, effectively ensuring the quality of port oil products and controlling the use of energy. At the same time, professional training for port staff has further improved the professionalism of the energy management team. These measures have promoted the coordinated development of Shanghai Port's production with resource and environment, and have a significant impact on the construction of a green port.

5.2. Developing Green Port Construction Plans

SIPG promotes the sustainable development of ports as well as the construction of green ports. On the basis of the aforementioned two plans, the "Summary Draft (Adjustment Report) of Key Support Projects for Shanghai Port Group's Theme Project of Creating a Green Port" was revised in 2016. The plan is to implement 25 key support projects, including RTG hybrid power transformation, automation terminal construction, clean energy applications such as LNG, port ship shore based power supply, green lighting, and information platform construction. In 2017, it will focus on the completion of the Green Port Three Year Action Plan (2015-2017) project. The results of the acceptance of the Green Port three-year action plan project in 2018 showed that the total energy savings were approximately 91000 tons of standard coal, replacing nearly 4000 tons of standard oil as fuel, and reducing carbon emissions by 132000 tons. In the 14th Five Year Plan of SIPG, it is clearly stated that the group will adhere to promoting the construction of smart ports, green ports, technological ports, and efficient ports.

5.3. Promoting Extensive Energy-saving and Emission Reduction

Shanghai Port continuously uses shore power to reduce carbon emissions. In 2016, the shore based power supply project for berth 1 of Shanghai Wusong International Cruise Port was completed and put into operation, which is the first and largest cruise ship frequency conversion shore power system in Asia and the world. At the end of 2017, 9 sets of shore power

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equipment had been built, including 2 sets in Guandong, 3 sets in Yangshan Phase IV, 2 sets in Guoke, and 2 sets in Wusongkou Cruise Port. The use of shore power in Shanghai ports can reduce pollutant emissions by up to 95% for each ship's docking. In addition, Shanghai Port continues to carry out a series of energy-saving and emission reduction measures such as updating diesel powered trucks, phasing out yellow labeled vehicles, carrying out energy-saving transformation of LED lighting, developing hybrid tugboats, and carrying out technical transformation of gas-electric hybrid RTG and oil-electric hybrid RTG. This has led to the continuous updating and transformation of old equipment, and the promotion and application of green equipment and technology in the port. In 2020, the green power RTG ratio of Shanghai Port reached 87%, and the proportion of main production equipment using clean energy reached the industry-leading level.

5.4. Constructing an Automated Port

The Yangshan Phase IV Automation Terminal has applied advanced technologies such as remote control bridge cranes, fully automatic track cranes, fully electric driven AGVs, intelligent scheduling systems, second-generation port ship shore based power supply, energy-saving new light sources, and solar assisted heating in its construction. The application of advanced technology has given Yangshan Phase IV Terminal more prominent advantages in energy conservation, emission reduction, environmental protection, and other aspects compared to traditional container terminals, and has also laid a solid foundation for building a zero emission green terminal. At present, the loading and unloading production design of Yangshan Phase IV has a comparable energy comprehensive unit consumption of only 1.58 tons of standard coal per 10000 tons of throughput, reaching the advanced international level.

6. The Developing Path of Low-carbon Technology in Ports

6.1. Building an Environmental Management System

In order to build a clean and low-carbon energy system, the following measures can be taken. Focusing on the electrification of terminal energy use and the greening of power sources, we could promote coordinated efficiency reduction in pollution and carbon reduction. First, it is necessary to enhance the application of multi energy complementary distributed renewable energy micro-grids in ports, striving for the integration and development of ports and new energy, and achieving clean energy self-consistency in ports with conditions. Second, port operators should actively develop the proportion of green energy such as wind, photovoltaic, and tidal energy in the power supply of port terminals, in order to replace the share of electricity purchased by some power grids, and achieve a significant increase in the proportion of green energy, thereby reducing carbon emissions from port terminals.

6.2. Strictly Controlling the Carbon Emissions of Arriving Ships

To control the carbon emissions resulting from ships, ports on one hand need to strictly require arriving ships to decelerate, use shore power, and take carbon neutrality measures to compensate for carbon emissions in the port. On the other hand, from a systemic perspective, ports should not only actively reduce transportation links within the port and reduce empty traffic or empty container research, but also optimize the collection and distribution system, actively encouraging the development of collection and distribution modes such as feeder barges and inbound railways, whose energy consumption per unit of transportation capacity is much lower than that of road vehicles, which has a huge effect on reducing external carbon emissions of the port.

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6.3. Enhancing the Application of Equipment Electrification and "Emission Reduction" Technology

Regardless of the type of energy used, such as solar energy, wind energy, hydrogen energy, nuclear energy, etc., ports should accelerate the electric drive transformation of mechanical equipment to meet the driving system requirements that are more in line with clean standards, especially tire mounted container gantry cranes, forklifts, and transportation vehicles. For equipment that cannot undergo power system transformation before scrapping, emission control technologies should be adopted, such as the application of diesel particulate filters, selective catalytic reduction and denitrification technologies, to reduce port energy pollution. At the same time, installing energy feedback devices on large lifting machinery such as shore bridges and gantry cranes can feed back the regenerated electrical energy generated during motor speed regulation to the power grid for use by other equipment, further reducing energy consumption in the lifting machinery process, improving energy utilization efficiency, and indirectly reducing greenhouse gas emissions. In addition, ports should also improve the energy efficiency level of buildings and actively adopt efficient air conditioning systems, double glazed windows, LED lights, or other energy-saving lighting systems.

6.4. Strictly Controlling the Carbon Emissions of Arriving Ships

For one thing, ports need to strengthen the construction of offshore digital port information platforms to provide real-time information for upstream and downstream enterprises in port activities, in order to better coordinate, plan, and allocate port resources. Such platforms could lead to more efficient scheduling of arriving ships and logistics vehicles, achieving seamless integration of cargo loading and unloading, ship refueling, ship resupply, repair and maintenance, thus enabling arriving ships to better optimize their sailing speed, route, or arrival time, in order to reduce ship waiting time and correspondingly reduce the exhaust emissions from their docking at ports, docks, and water areas. For another, ports should strengthen the application of intelligent algorithms. For example, developing advanced intelligent scheduling algorithms for port containers could realize automatic task allocation, optimal vehicle scheduling, optimal Bennet flipping, intelligent matching of vehicles and containers, and full process optimization of production operations, therefore innovating new modes of port container operation scheduling, and reducing carbon emissions.

7. Discussions

As a key carbon emitting unit in the water transportation industry, the energy-saving and emission reduction effects of ports are of great significance for the government to achieve emission reduction goals. This article analyzes the low-carbon technologies currently being applied in ports, and summarizes the effective practices of Shanghai Port in implementing low-carbon technologies. We chiefly focus on proposing the construction path for port development of low-carbon technologies from four aspects: clean low-carbon energy system, collection and distribution system, equipment electrification, and digital intelligent technology. The suggestions brought about by this article will have beneficial reference value for port energy conservation and emission reduction, and promote ports to participate in achieving the goals of "carbon peaking" and "carbon neutrality".

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