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Research on Green and Low-Carbon Transformation Path of the Shipping Industry Based on International Standards and Market Demand

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ABSTRACT
Amid global climate change efforts, the International Maritime Organization (IMO) and others have set ship emission standards and green low-carbon regulations to strictly limit sulfur and nitrogen oxide emissions. Concurrently, growing environmental awareness has boosted market demand for green low-carbon ships.This study proposes green low-carbon transformation paths for the shipping industry based on international standards and market needs, constructing a "standard-technology-market" collaborative analysis framework to address gaps in existing research regarding policy implementation and corporate practice alignment. Practically, it provides governments with a basis for designing "carbon tax + subsidy" policies and offers enterprises decision-making tools like "fuel substitution priority" and "technology roadmap formulation".

KEYWORDS
Shipping industry; Green and low-carbon transformation; International maritime organization (IMO); Emission standards; "Standard-technology-market" framework; Carbon tax + subsidy; Fuel substitution; Technology roadmap

1 Elaboration on Research Background and Significance

1.1 Global Climate and Shipping Emission Status

The global average temperature has risen by 1.1°C compared to pre-industrial levels. If current emission trends continue, the 2°C threshold will be exceeded by 2050. As a core carrier of international trade, the shipping industry emits 940 million tons of CO_2 annually, accounting for 3% of global emissions, with bulk carriers and container ships contributing over 70% of total emissions [01]. IMO research indicates that shipping-related SOx and NOx emissions account for 13% and 15% of global anthropogenic emissions, respectively, directly contributing to acid rain formation in coastal cities and increased respiratory disease incidence [02].

1.2 Multi-dimensional Analysis of Transformation Necessity

Environmental Dimension: IMO Initial Greenhouse Gas Strategy mandates net-zero emissions for the shipping sector by 2050, force the industry to eliminate high-carbon technologies.

Economic Dimension: Although green ship construction costs are 15–30% higher than traditional vessels, lifecycle fuel costs can be reduced by over 40%. For instance, Maersk's 24, 000 TEU methanol-powered ship has verified fuel cost savings of $280,000 per voyage [03].

Industry Competition Dimension: DNV data shows that green ship orders accounted for 52% of total orders in 2024, placing companies without low-carbon technology layouts at risk of market share erosion.

1.3 Value and Guiding Role of This Research

Theoretically, this study constructs a "standard-technology-market" synergy analysis framework, addressing gaps in existing research regarding policy implementation and enterprise practice integration. Practically, it provides governments with a basis for designing "carbon tax + subsidy" combined policies and offers enterprises decision-making tools such as "fuel substitution priority selection" and "technology roadmap development."

2 In-depth Analysis of International Standards and Demands

2.1 Interpretation of International Maritime Organization (IMO) Standards

The 2025 amendments to IMO MARPOL Annex VI establish a "staged carbon intensity standard":

•2027–2030: Ship fuel carbon intensity reduction of 30% compared to 2008 levels;

•2030–2040: Further reduction of 43%;

•Post-2040: 10% reduction every five years [04].

Compliance mechanisms adopt a "reward-penalty" system: Ships using green ammonia (carbon intensity <19 g CO_2 eq/

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MJ) qualify for a $200 subsidy per ton of CO_2, while excessive emissions incur fines of up to $380 per ton. Covering 85% of global shipping emissions, this standard is projected to reduce industry CO_2 emissions by 120 million tons annually upon its 2027 enforcement.

2.2 Relevant Requirements from Other International Organizations

The EU ' s FuelEU Maritime Regulation further specifies regional standards:

2025: 2% reduction in ship fuel carbon intensity vs. 2020;

2030: 13% reduction;

2050: Full lifecycle zero emissions.

Its innovation lies in the dual-track system of Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII). Ships rated CII Class D must submit rectification plans within six months or face EU port entry bans [05]. The California Air Resources Board (CARB) imposes stricter NOx standards on ships calling at Los Angeles Port, requiring a 50% reduction compared to IMO Tier III.

2.3 Market Demand Characteristics and Trend Insights

Shipper Side: Major companies like IKEA and Unilever have signed forward-looking "Green Shipping Agreements," mandating carriers to use zero-carbon fuels for 50% of shipping capacity by 2030, with non-compliant partners facing contract termination risks.

Port Side: Shanghai Port offers up to 50% port fee discounts for ships using shore power, driving international container ship shore power utilization from 12% (2020) to 68% (2024) [06].

Financial Side: The London insurance market has increased premiums for high-emission ships by 20 – 50% while offering preferential rates and priority claims processing for green-compliant vessels.

3 Assessment and Comparison of Transformation Status

3.1 Foreign Transformation Achievements and Experiences

Norway leads in technological R&D:

•The all-electric container ship “Yara Birkeland” achieves zero emissions with a 7 MWh battery capacity (equivalent to ~ 1,000 Tesla Model 3s).

•DNV GL ' s "Ammonia Fuel Safety Code" has gained international recognition as a global industry standard.

The EU has pioneered policy innovation through its Carbon Border Adjustment Mechanism (CBAM), imposing additional carbon taxes on imported high-carbon ship products to drive low-carbon transformation in global supply chains.

3.2 Domestic Transformation Progress and Gaps

China has made breakthroughs in green shipbuilding:

Hudong-Zhonghua Shipbuilding developed an 18,000 TEU LNG-powered container ship using "membrane fuel tank + dual-fuel engine" technology, reducing energy consumption by 20% compared to conventional vessels.

China Classification Society (CCS) updated its Green Ship Rules to the 4th edition, covering 80% of low-carbon technology application scenarios.

However, core components remain heavily import-dependent: 80% of ship batteries rely on South Korea ' s Samsung SDI;

Ammonia fuel engine control systems are monopolized by Germany ' s MAN Energy Solutions;

Resulting in a localization rate of less than 15% in this critical field in China [07].

4 Exploration of Technological Innovation Paths

4.1 Development and Application of Alternative Fuels

Short-term Transition (2025–2030): LNG dominates due to mature supply chains (China builds 53% of the world ' s 1, 329 LNG-powered ships). IMO regulations require 30% biomethane blending, but current biomethane costs (2.3× conventional LNG) hinder large-scale adoption [08].

Mid-term Mainstream (2030 – 2040): Methanol is preferred for high energy density (22.7 MJ/kg) and low refueling infrastructure retrofitting cost (~$5 million/port). Yangzhou COSCO Shipping Heavy Industry ' s 24,000 TEU methanol dual-fuel ship uses a "WinGD 12X92DF engine + methanol storage tank" system, consuming ~12, 000 tons of methanol annually, reducing CO_2 emissions by 120,000 tons/year with an 8-year investment payback period [09].

Long-term Zero-Carbon (Post-2040): Green hydrogen (produced via renewable energy) and green ammonia (synthesized from green hydrogen) are ultimate goals. Yara International's "renewable ammonia production" technology has reduced costs to $2.8/kg, but cryogenic storage requirements (-33°C) increase ship construction costs by 40% [10].

4.2 Energy Efficiency Improvement and Smart Technology Application

Hull Optimization:

Jiangnan Shipyard's "bulbous bow + energy-saving appendages" design reduces 300,000 DWT VLCC resistance by 8% and increases speed by 2 knots.

Hudong-Zhonghua's "air lubrication system" reduces friction via hull bubble layers, achieving 12% fuel savings per voyage.

Smart Operations: COSCO Shipping uses digital twin technology for real-time speed/route adjustments, reducing fuel consumption by 15% and carbon emissions by 18% on the Shanghai-Rotterdam route [11].

5 Analysis of Policy Support Paths

5.1 Domestic Policy Incentives and Guidance Measures

Central Level:

The Ministry of Finance established a "Green Ship Construction Special Fund" offering ¥2, 000/Deadweight Ton subsidies (max. ¥200 million/ship) for methanol-powered vessels.

The State Taxation Administration implements "tax credit" policies for energy-efficient equipment purchases, with credits up to 10% of equipment investment.

Local Level: Shenzhen piloted "carbon quota pledge financing," allowing ship enterprises to pledge carbon allowances for loans with 30% interest rate discounts, facilitating ¥1.2 billion in financing for 5 enterprises [12].

5.2 Policy Coordination and Implementation Effect Evaluation

Current challenges include "standard fragmentation": Differences between IMO carbon intensity standards and EU FuelEU calculation methods may subject ships to dual accounting. Proposed solutions:

Establish an "international standard mutual recognition mechanism."

Pilot carbon intensity accounting mutual recognition between CCS and Lloyd's Register (LR), projected to reduce enterprise compliance costs by 35%.

6 Research on Market Mechanism Paths

6.1 Industrial Chain Collaborative Development Model

Sinopec and COSCO Shipping jointly built a "green fuel supply chain":

A 500, 000-ton green methanol production base in Zhoushan Port, supported by 3 methanol refueling stations, forming an integrated "production-storage-refueling" network.

This model reduces methanol procurement costs by 18% and increases refueling efficiency to 500 tons/hour [13].

6.2 Innovation and Improvement Directions for Market Mechanisms

The Shanghai Environment and Energy Exchange launched "shipping carbon quota futures," with 2024 trading volume reaching 8 million tons, providing enterprises with carbon price risk management tools. Recommendations include expanding traded varieties to introduce "fuel carbon intensity futures" for locking long-term procurement costs of green ammonia/methanol.

7 Discussion on Enterprise Management Paths

7.1 ESG System Construction and Implementation Key Points

China State Shipbuilding Corporation established a three-tier ESG management framework:

Sustainability Committee under the Board of Directors;

ESG Management Department at headquarters;

Dedicated ESG positions in subsidiaries.

Its 2024 ESG report disclosed 28 key performance indicators (KPI), including "green ship order ratio" and "energy consumption per unit output value," representing a 120% improvement since 2020 [14].

7.2 Digitalization and Lean Management Methods

Jiangnan Shipbuilding applied "digital twin factories":

•3D modeling and real-time data collection shortened shipbuilding cycles by 25%.

•Steel utilization rates increased from 85% to 92%, reducing annual waste emissions by 12,000 tons.

Recommendations include promoting "modular construction" to increase hull section prefabrication rates to over 90% for further energy reduction.

8 Case Analysis and Enlightenment

8.1 Domestic Typical Case

COSCO Shipping Group's "Methanol Power Transformation Three-Step Strategy":

2023: Ordered 30 methanol dual-fuel ships.

2025: Completed Zhoushan methanol refueling center.

2030: Achieve 50% methanol-powered fleet for COSCO Shipping Lines.

Innovation lies in "Fuel Supply Agreements (FSA)" for price locking: A 10-year green methanol procurement agreement with Xinjiang Guanghui Energy locks prices at $280/ton (15% below spot prices) [15].

8.2 International Typical Case

Norway's "Oslo Zero-Emission Port Model" uses a "carbon credit" system to incentivize low-carbon ship behavior:

(1) credit/hour for shore power usage;

(2) credits/ton for green ammonia fuel;

Credits redeemable for 50% port fee discounts or Norwegian carbon sink allowances.

This model reduced port emissions by 42% (vs. 2019) and attracted 23 global shipping companies to establish headquarters there [16].

9 Conclusions and Recommendations

The shipping industry's green low-carbon transformation requires breaking through "technology-policy-market" bottlenecks:

Technology: Accelerate cost reduction of green hydrogen electrolyzers to <$1/W.

Policy: Promote mutual recognition between IMO carbon taxes and EU ETS to avoid double charging.

Market: Develop "transoceanic green fuel corridors" connecting hubs like Zhoushan (China), Singapore, and Rotterdam (Europe).

Enterprises should prioritize methanol/ammonia-powered ship layouts, participate in carbon trading markets, and sign "take-or-pay" fuel supply agreements with energy companies to ensure transformation stability.

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