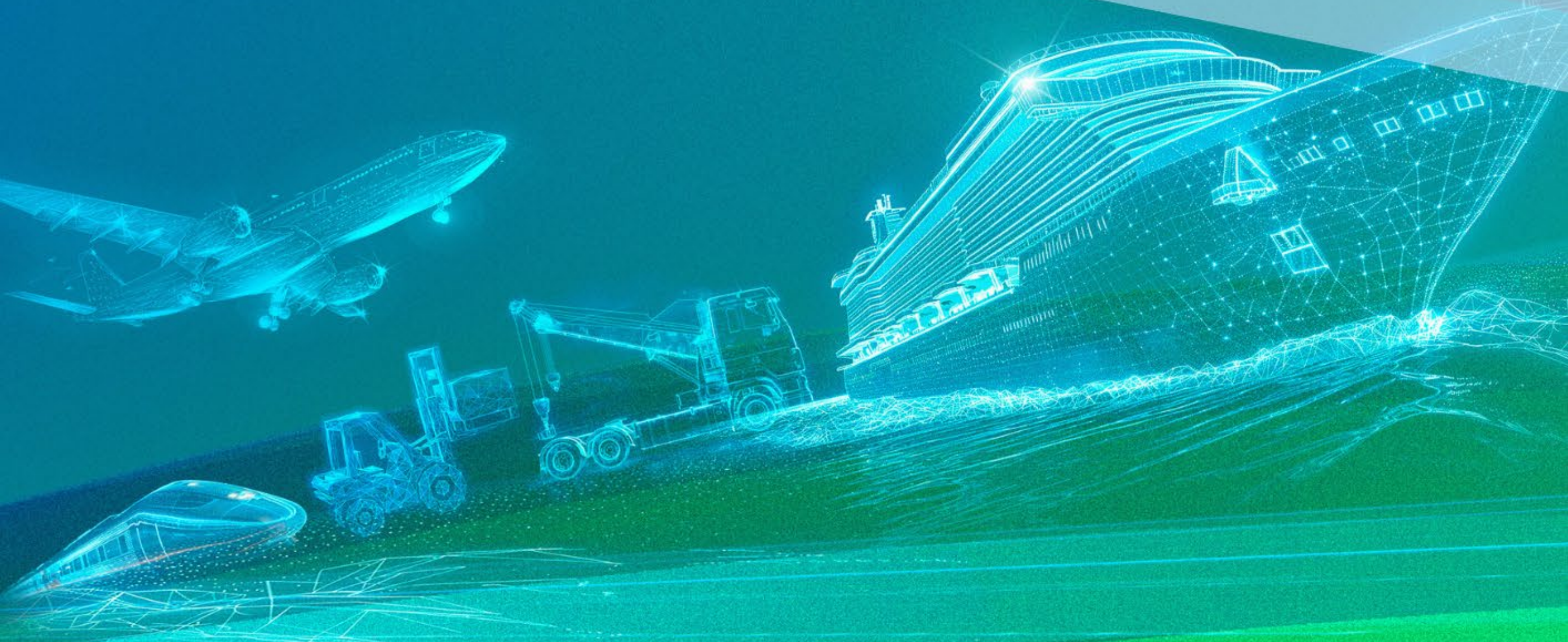
Report Series of *Blue Book on China's Zero-Emission Transformation in Transportation*

Towards Zero Emissions: Green Transition and Prospects in China's Non-Road Transportation

—— China Clean Transportation Partnership
2024 Annual Comprehensive Research



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- "Blue Book on China's Zero-Emission Transformation in Transportation" series

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About China Clean Transportation Partnership

The China Clean Transportation Partnership (CCTP) is a non-governmental, non-profit, and voluntary platform that fosters cross-sectoral and cross-regional cooperation, knowledge sharing, joint research, and communication by engaging with top research institutes and think tanks in the field of transportation, energy, climate, environment, and sustainable development. The partnership was formed by leading institutions in China to promote innovations in clean transportation, with the core values of Independence, Professionalism, Sharing, and Inclusivity. The CCTP Secretariat is currently located at the Innovation Center for Energy and Transportation.

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(Sorted in alphabetical order.)

Preface

Climate change has become a pressing global issue, with escalating climate risks and global carbon emissions reaching record highs post-pandemic. Significant gaps persist in climate action, particularly in mitigation, adaptation, and funding between developed and developing nations. Geopolitical conflicts further complicate global solutions. Despite these challenges, momentum for green transitions is growing. "Carbon neutrality" has become a worldwide priority, with initiatives like the first global stocktake of climate progress paving the way for stronger action and financial targets at COP29 to support low-carbon transitions in developing countries.

Transportation, responsible for over a quarter of global greenhouse gas emissions, is critical to achieving sustainable development and Paris Agreement goals. As a major transportation nation, China is actively promoting a sustainable transition through advancements in new energy, smart, digital, and lightweight technologies, alongside green travel initiatives.

China's progress in new energy vehicles (NEVs) and low-carbon fuels has garnered international recognition. By mid-2024, NEV ownership in China reached 24.72 million, with new energy passenger vehicles capturing 45% of the monthly market. Annual production and sales consistently surpass 10 million units, maintaining a dominant global market share. As a leader in renewable energy, China's installed capacity exceeded 1.5 billion kilowatts in 2023, nearly 40% of the global total. The country also leads in hydrogen production, launching 74 renewable hydrogen projects in 2023, including Sinopec's Kucha Green Hydrogen Project, the largest photovoltaic-powered facility in China. Green hydrogen and its derivatives like ammonia and methanol are expected to drive low-carbon energy transitions across sectors, including transportation.

However, achieving a green, low-carbon transportation system poses significant challenges, especially in non-road sectors. Barriers such as high costs, outdated equipment, and technical limitations complicate electrification in non-road mobile machinery. Shipping faces hurdles from small, aging inland fleets to uncertainties in green fuel technology and insufficient supply. Aviation remains constrained by limited sustainable aviation fuel (SAF) production and high costs, alongside the absence of a long-term development plan in China.

Since 2022, the China Clean Transportation Partnership (CCTP) has compiled the *Blue Book on China's Zero-Emission Transformation in Transportation* series, providing valuable references for the low-carbon development of China's transportation sector. This volume focuses on the non-road transportation sector, examining sub-sectors like non-road mobile machinery, inland shipping, aviation, and railways. Through analyses of technological pathways and emission reduction potential, it offers policy recommendations for achieving zero emissions in these areas.

This book reflects the collective expertise of numerous organizations, including Chinese Research Academy of Environmental Sciences, the International Council on Clean Transportation, Pacific Environment, Wuhan Changjiang Ship Design Institute Co., Ltd., Clean Air Asia, Civil Aviation University of China, Beihang University, Beijing Jiaotong University, and Cathay Pacific. CCTP's Executive Committee and Secretariat facilitated discussions, reviews, and compilation efforts, with valuable feedback from the Energy Foundation's Transportation Program team.

On behalf of the CCTP Executive Committee and Secretariat, I sincerely thank all the experts and institutions for their contributions and support. Given time and resource constraints, some oversights and shortcomings may remain. We sincerely welcome valuable suggestions for improvement from experts, colleagues, and readers.

王敬武

Director of the CCTP Executive Committee

October 2024

Abstract

The transportation sector is one of the major sources of greenhouse gas emissions, and its transition to zero emissions has become a global priority. As the world's largest greenhouse gas emitter, China's low-carbon transition in transportation is crucial not only for advancing domestic high-quality development but also for significantly impacting global climate governance. Currently, transportation accounts for approximately 10% of China's total greenhouse gas emissions, a proportion expected to increase with economic and social development. Despite remarkable achievements in the NEV industry, railway electrification, and the use of shore power for ships, significant challenges remain in the green and low-carbon transition of transportation. The non-road transportation sub-sector, in particular, faces pronounced difficulties in achieving zero emissions.

To advance low-carbon transitions in these areas, the China Clean Transportation Partnership (CCTP) organized industry institutions and experts to jointly compile *Towards Zero Emissions: Green Transition and Prospects in China's Non-Road Transportation*. As part of the *Blue Book on China's Zero-Emission Transformation in Transportation series*, this book delves into critical areas beyond road transportation emission reductions, covering the green and low-carbon transformation of non-road mobile machinery, shipping and ports, aviation, and high-speed rail. By analyzing the current status and challenges of low-carbon transitions in these transportation sectors, the book offers detailed policy recommendations and technological pathways for future progress. It serves as a comprehensive reference for policymakers, industry professionals, researchers, and the public. The book is divided into four chapters: Non-Road Mobile Machinery, Shipping and Ports, Aviation, and Transport Structure Adjustment (Passenger Transport).

The chapter on non-road mobile machinery examines the development status and pollution-reduction trends both domestically and internationally. The United States and the European Union are leading the transition to zero emissions in this sector through stringent emission standards, zero-emission targets, and financial and tax incentives. In comparison, China has made progress in electrifying construction and agricultural machinery but still faces challenges such as high pollutant emissions and difficulties in phasing out outdated equipment. The study recommends strengthening policy support, accelerating the elimination of old machinery, and implementing stricter emission standards. Incentives such as financial subsidies and tax benefits should be used to encourage enterprises to develop and adopt new energy technologies. Establishing demonstration zones is also proposed to further

accelerate the green transition of non-road machinery.

The chapter on shipping and ports reviews emission reduction policies and practices at the international, regional, and industry levels. The International Maritime Organization (IMO) introduced its initial greenhouse gas (GHG) reduction strategy in 2018, targeting a 50% GHG reduction by 2050, which was updated in 2023 to a net-zero emissions goal. China has made progress in the low-carbon transition of inland and coastal shipping, particularly through the adoption of new energy vessels, the promotion of shore power facilities, and the optimization of port operations, effectively reducing GHG emissions. This chapter analyzes domestic and international pathways and technological applications for emission reduction, recommending the advancement of green vessel technologies such as electric, hydrogen-powered, and hybrid ships. It emphasizes the widespread adoption of shore power facilities to enable docked ships to operate using clean electricity. Strengthening collaboration with the IMO and other nations is also advised to develop and implement international green shipping standards, ensuring the competitiveness of China's shipping industry in global markets and achieving sustainable development goals for the shipping and port sectors.

The aviation chapter analyzes future demand forecasts, the current state of carbon emissions, and future trends in the sector. It explores the potential of sustainable aviation fuel (SAF) and proposes several emission reduction measures, including the promotion of SAF and the development of electric aircraft. The chapter also highlights the importance of international cooperation, calling for globally unified carbon emission standards and reduction targets to drive the aviation industry's green and low-carbon transition.

The chapter on transport structure adjustment—passenger transport explores the development, energy consumption, and emission status of high-speed rail (HSR), with a focus on its potential to replace short-haul air travel and strategies to promote this transition. Given HSR's advantages in energy efficiency and emission reduction, it is expected to play a key role in optimizing transport structures, including shifts from air to rail for passengers and from road to rail for freight. The chapter recommends prioritizing HSR for medium and short-distance travel, leveraging its low-carbon and efficient advantages to replace air travel. Additionally, it emphasizes expanding the HSR network to meet more medium- and short-distance transport demands and accelerating the power sector's green transition. Increasing the share of renewable energy in electricity generation will fundamentally reduce the carbon footprint of HSR operations.

Considering China's specific circumstances and global climate goals, this book advocates for a comprehensive policy mix to ensure the sustainable development of China's transportation sector under its "dual carbon" targets. Guided by the nation's "dual carbon" strategy, the low-carbon transition of transportation has become a key focus for both the government and industry. This book systematically reviews the current status and future trends in China's non-road mobile machinery, shipping, aviation, and passenger transport structure adjustment. It provides an in-depth analysis of the challenges and issues these sectors face in achieving zero-emission goals and offers targeted technological pathways and policy recommendations. Through detailed research and discussion across various fields, the book delivers the latest insights and future directions for the zero-emission transition of non-road transportation. It serves as a valuable reference for government agencies in formulating policies and regulations and provides crucial support for enterprises in crafting low-carbon strategies and technical plans.

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Abbreviations

Abbr.	Full English Name
AAM	Advanced Air Mobility
ACI	Airport Council International
ASTM	American Society for Testing Material
ATS	SI engines used in all terrain and side-by-side vehicles
CCS	China Classification Society
CH_4	Methane
CHJ	Catalytic Hydrothermolysis Jet Fuel
CII	Carbon Intensity Indicator
CO_2	Carbon Dioxide
COP	Conference of the Parties to the United Nations Framework Convention on Climate Change
CORE	Clean Off-Road Equipment Voucher Incentive Project
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSR	Corporate Social Responsibility
DEP	Distributed Electric Propulsion
DPF	Diesel Particulate Filter
EASA	the European Aviation Safety Agency
EEXI	Energy Efficiency Existing ship Index
EIA	Energy Information Administration
EIB	European Investment Bank
ESG	Environmental, Social, and Governance
EU ETS	European Emissions Trading Scheme
eVTOL	Electric Vertical Takeoff and Landing
FAA	Federal Aviation Administration
FT	Fischer-Tropsch
GFS	Greenhouses Gas Fuel Standard

GHG	Greenhouse Gases
HC	Hydrocarbons
HEFA	Hydroprocessed Esters and Fatty Acids
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICCT	International Council On Clean Transportation
IEA	International Energy Agency
IMO	International Maritime Organization
ISCC	International Sustainability & Carbon Certification
IWA	Auxiliary engines above 19 kW for use in inland waterway vessels
IWP	Engines above 19 kW used for direct or indirect propulsion of inland waterway vessels
KOCA	Korea Civil Aviation Authority
LATG	Long-Term Aspirational Goal
LCFS	Low Carbon Fuel Standard
LED	Light Emitting Diode
LEZ	Low Emission Zone
LNG	Liquefied Natural Gas
LTO	Landing and Takeoff
MTJ	Methanol To Jet
N_2O	Nitrous Oxide
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
NRE	Engines for mobile Nonroad machinery
NRG	Engines above 560 kW used in generating sets
NRS	SI engines below 56 kW that are not included in category NRSh
NRSh	SI engines below 19 kW exclusively for use in hand-held machinery
OBD	On-Board Diagnostics
OMV	Österreichische Mineralölverwaltung Aktiengesellschaft

OSTP	Office of Science and Technology Policy
PEMFC	Proton Exchange Membrane Fuel Cell
PM	Particulate Matter
PtL	Power to Liquid
RED	Renewable Energy Directive
RFS	Renewable Fuel Standard
RLL	Engines for the propulsion of railway locomotives
RLR	Engines for the propulsion of railcars
RSB	Roundtable on Sustainable Biomaterials
RTG	Rubber Tired Gantry crane
SAF	Sustainable Aviation Fuel
SAK	Synthetic aromatic kerosene
SBTi	Science Based Targets Initiative
SCR	Selective Catalytic Reduction
SGMF	Society for Gas as a Marine Fuel
SIP	Synthesized iso-paraffins
SKA	Synthesized kerosene with aromatics
SMB	SI engines used in snowmobiles
SOFC	Solid Oxide Fuel Cell
SPK	Synthetic paraffinic kerosene
SSEB	Subsidy for Clean and Zero Emission Construction Equipment
TEU	Twenty Feet Equivalent Unit
UNFCCC	The United Nations Framework Convention on Climate Change
WTW	Well-to-Wheels
ZEZ	Zero Emission Zone

I Non-Road Mobile Machinery Section

This section provides a detailed overview of the status and trends in pollution reduction and carbon reduction in the non-road mobile machinery sector, both internationally and domestically. Currently, the United States and the European Union have made some progress in the electrification of non-road mobile machinery, while China has also achieved significant success in promoting the electrification of construction and agricultural machinery. In the future, measures such as financial subsidies, environmental information disclosure, coding registration, and the establishment of high-emission machinery prohibition zones will further promote pollution and carbon reduction efforts in non-road mobile machinery. Based on international experience and domestic conditions, this section proposes policy recommendations to further improve laws and regulations, establish integrated regulatory platforms, and implement joint regulation by multiple departments.

Keywords: Non-Road Mobile Machinery, Pollution Reduction and Carbon Reduction, Electrification, Emission Standards, Phasing Out Old Machinery, Green and Intelligent Development

This section combines the analysis and research of Dr. Xie Shuxia, Associate Researcher at the Vehicle Emissions Monitoring Center of the Chinese Research Academy of Environmental Sciences, with the research findings from the International Council on Clean Transportation's briefing on "Promoting Zero-Emission Non-Road Machinery."

Note: The non-road mobile machinery discussed in this section mainly refers to construction machinery and agricultural machinery used in sites such as construction, mining, port handling, and airport ground support. Locomotives, ships, aircraft, and other broadly defined non-road mobile machinery will be discussed and analyzed in other chapters of this book.

Chapter I Non-Road Mobile Machinery Section

1. What is the definition of non-road mobile machinery?

The definition of non-road mobile machinery varies slightly among major countries, with similarities and differences. This section focuses on examples from the United States, the European Union, and China.

United States

The United States began research on non-road mobile machinery relatively early and has established a comprehensive management system. Non-road mobile machinery in the U.S. is categorized into five types: land-based diesel engine machinery, land-based spark-ignition machinery, marine engines and vessels, locomotives, and aircraft, as shown in Figure 1.

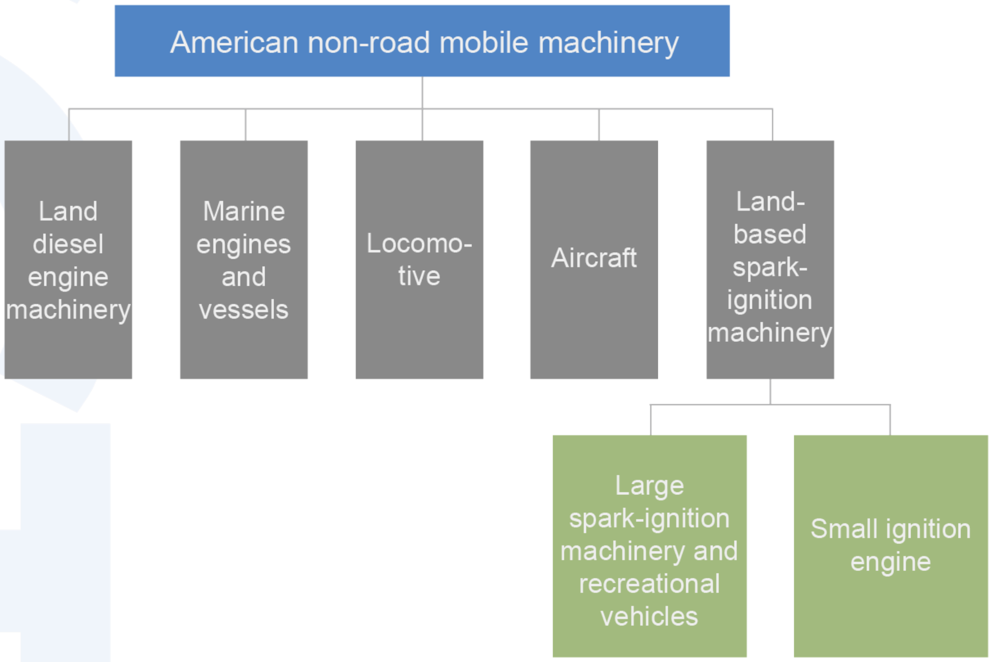

Figure 1 Classification of Non-Road Mobile Machinery in the United States[1]

European Union

The European Union defines and categorizes non-road mobile machinery primarily based on engine types, as shown in Table 1. The EU's non-road machinery market plays a significant role on the global stage.

[1] HU Mingwei, TANG Jingyan, LIU Peng, et al. Comparative Analysis on the Emission Standards of Non-Road Mobile Machinery in China, the Europe and the US [J], *Chinese Journal of Environmental Management*, 2021(3): 66-73.

Table 1 Classification of Non-Road Mobile Machinery in the European Union[2]

Engine Name	Scope of Application	Rated Net Power Range
NRE	Engines used in mobile non-road machinery that are either self-propelled or towed, excluding the following categories.	-
NRG	Engines with a power output greater than 560kW, which are used in generator sets.	>560kW
NRSh	Engines with a power output less than 19kW, specifically designed for handheld ignition engines.	<19kW
NRS	Ignition engines with a power of less than 56kW, excluding those in the NRSh category.	<56kW
IWP	Engine with a reference power of not less than 19kW for inland vessels.	≥19kW
IWA	Auxiliary engines for inland vessels with a reference power greater than or equal to 19kW.	≥19kW
RLL	Engines used in railway locomotives.	-
RLR	Engines for railcars.	-
SMB	Ignition engines for snowmobiles.	-
ATS	Ignition engines for dune buggies and all-terrain vehicles.	-

China

China classifies non-road mobile machinery in various ways depending on the application. Typically, it is categorized by usage into construction machinery, agricultural machinery, gardening machinery, generator sets, fishery machinery, and airport ground support equipment. Among these, construction and agricultural machinery are the primary types of non-road diesel mobile machinery, as shown in Table 2.

[2] https://eur-lex.europa.eu/legalcontent/EN/TXT/HTML/?uri=CELEX:52023SC0065

Table 2 Classification Table of Non-Road Mobile Machinery

Category	Description
Construction machinery	A general term for construction and engineering machinery, primarily fueled by diesel. It includes excavators, bulldozers, loaders, forklifts, road rollers, pavers, graders, and other machinery, etc.
Agricultural machinery	Various machines are used in the production processes of crop farming and animal husbandry, as well as in the preliminary processing and handling of agricultural and livestock products, primarily fueled by diesel. It includes tractors, agricultural transport vehicles (agricultural machinery license plates), combine harvesters, irrigation and drainage machinery, and other machinery, etc.
Small general-purpose machinery	Non-road mobile machinery powered by small ignition engines with net power not exceeding 19 kW, including lawn mowers, chainsaws, generators, water pumps, brush cutters, etc.
Diesel generator sets	Mobile generator sets that operate at a constant speed and are fueled by diesel.

2. What is the development status of non-road mobile machinery in major countries and regions globally?

The green transition of non-road mobile machinery has become a global consensus, with countries making significant efforts in policies, technologies, and markets to support this goal. The international non-road mobile machinery market, particularly in the U.S. and EU, has made notable progress in green transformation and emissions reduction. Governments employ various approaches, including regulatory frameworks, fiscal and tax incentives, and market mechanisms, to promote the green transition of non-road mobile machinery. The U.S. and EU are leading in this effort,[3] setting benchmarks for other regions in advancing sustainable practices in this sector.

United States

In the construction machinery sector, battery-powered compact excavators accounted for 5% of the U.S. market in 2021. By 2029, the highest electrification

[3] Citing a briefing paper titled *Incentivizing Zero-Emission Off-Road Machinery* by the International Council on Clean Transportation

rates are projected for compact excavators (9% in both the U.S. and California), wheel loaders (6% in both regions), backhoe loaders (9%), and skid-steer/track loaders (11% for both). However, hydrogen fuel cell innovation and development lag significantly behind battery power, both in scale and application across multiple fields.

In the agricultural machinery sector, as of August 2022, 57 battery-powered tractors were sold in the U.S., representing only 0.02% of total tractor sales. By 2029, over 3,000 battery-powered tractors are expected to be sold annually, accounting for nearly 1% of total U.S. tractor sales. Additionally, hybrid electric tractors are projected to make up about 8% of annual sales, exceeding 21,900 units. In California, approximately 12% of the 8,000 tractors sold annually by 2029 will be battery-powered, while 8% will be hybrid-powered.

European Union

The EU leads in forklift electrification, driven by indoor zero-emission regulations, making electric forklifts increasingly common. Manufacturers such as Clark, Doosan, Hyundai, Mitsubishi, Komatsu, Toyota, Jungheinrich, and Linde dominate the mainstream market with a range of electric forklifts from small to medium-sized models, including three- and four-wheel designs. Electric forklifts are particularly advantageous in indoor warehouses with minimal relocation requirements, offering up to 75% savings in operating costs compared to propane-powered vehicles. Notably, hybrid aerial work platforms account for 4% of the European market.

Unlike forklifts and aerial platforms, the EU's progress in excavator electrification has been slower but is now gaining momentum. By 2029, electric mini-excavators in the UK are projected to capture 15% of the market, primarily relying on battery technology. Mini-excavators are advancing further in electrification than mid-to-large excavators in Europe. Companies like Komatsu and Volvo showcased electric mini-excavators at the 2019 bauma trade fair in Munich. In early 2020, Volvo launched its first mass-produced electric mini-excavator, the ECR25. JCB and German manufacturer Wacker Neuson also introduced electric mini-excavators, including the 19C-IE and EZ17, emphasizing zero emissions and high efficiency as key selling points.

Of particular interest is Yanmar's strategy to eliminate hydraulic fluid in excavators. In 2019, Yanmar unveiled a prototype mini-excavator using three electric actuators to replace hydraulic cylinders, achieving a fully oil-free design.

The electrification of concrete mixers in the EU began in early 2020, led by Liebherr's launch of the world's first fully electric five-axle concrete mixer, based on the Volvo FM electric truck. With a power output of 670 hp (approximately 492 kW), it achieved complete electrification. Subsequently, CIFA introduced the first hybrid concrete mixer, featuring a diesel engine paired with a lithium battery supporting fast charging at 380/400 V and 75 kW, enabling an 18-minute full charge during loading operations to enhance efficiency. Putzmeister followed with its iONTRON technology, launching the world's first electric concrete pump truck. Unlike the previous models, Putzmeister's pump relies on direct electric power via cables, while diesel engines provide power for movement and boom extension.

3. What international experiences can be referenced for transitioning to zero-emission non-road mobile machinery?

Over the past two decades, the rapid growth of the global non-road mobile machinery market has led to a corresponding increase in emissions. Compared to on-road vehicles, emission regulations for non-road machinery have lagged behind, making these machines a major source of emissions in many regions. To address this, numerous countries have introduced various policy measures to encourage the transition to zero-emission non-road machinery. Regulatory authorities in key regions have set timelines for zero-emission machinery sales, and pilot projects are underway.

Measures to promote zero-emission non-road machinery can be categorized into four types: policy and regulations, financial and tax tools, market mechanisms, and industry strategies. Many major markets have adopted a combination of regulatory requirements and fiscal incentives to accelerate the transition, while some have initiated pilot projects. Figure 3 summarizes 12 types of measures supporting zero-emission non-road machinery.

Although most existing measures are still in the early stages, global attention to these policies is rapidly increasing[3].

Figure 2 Global Measures for Promoting Zero-Emission Non-Road Machinery That Have Been Implemented and Planned

Figure 3 Summary of International Measures for Achieving Zero Emissions in Non-Road Mobile Machinery

(1) Policy and regulations

Different countries have introduced various policies to promote the clean transition of non-road mobile machinery, including setting zero-emission targets, establishing emission standards, designating low- and zero-emission zones, restricting diesel machinery, and implementing noise control measures.

i.*Setting zero-emission targets*

Zero-emission targets set requirements for the sale of zero-emission machinery. These targets are typically announced by governments and can be either binding or non-binding. For example, California has announced a goal of achieving 100% zero emissions for in-use non-road mobile machinery "where feasible" by 2035. New York State has proposed a non-binding target of achieving 100% zero emissions for new sales of non-road mobile machinery by 2035[4]. Chile aims to achieve 100% zero emissions for new machinery sales over 500kW by 2035[5], and for machinery between 19kW and 500kW by 2040[5]. In Europe, Finland has set a goal of achieving 100% fossil-fuel-free construction sites by 2025. [6]

California's zero-emission fleet targets.

In recent years, non-road diesel engine emissions in California have accounted for 29% of the state's diesel particulate matter (PM) emissions and 11% of nitrogen oxide (NOx) emissions. [7]The Governor of California signed an executive order directing the California Air Resources Board (CARB) to develop a strategy for transitioning all in-use non-road mobile machinery to zero emissions "where feasible" by 2035. California has already implemented several regulatory measures and is considering new requirements to support

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[4] California Air Resources Board. (2020). Zero-Emission Off-Road Strategy. https://ww2.arb.ca.gov/sites/default/files/2020-11/ZEV_EO_Off-Road_Fact_Sheet_111820.pdf; New York State (2021). Ahead of Climate Week 2021, Governor Hochul Announces New Actions to Green New York's Transportation Sector and Reduce Climate-Impacting Emissions. https://www.governor.ny.gov/news/advance-climate-week2021-governor-hochul-announces-new-actions-make-new-yorks-transportation

[5] O. Delgado and S. Petigru (2022), Chile's New Legislation Demonstrates Climate Leadership. https://theicct.org/chile-latam-lvs-legen-apr22/

[6]Bellona Europa (2020), Finland Starts Setting Emission Targets for the Construction Sector. https://bellona.org/news/eu/2020-05-finlandstarts-targeting-emissions-in-the-construction-sect

[7]California Air Resources Board (2020), Zero-Emission Off-Road Strategy. https://ww2.arb.ca.gov/sites/default/files/2020-11/ ZEV_ EO_Off-Road_Fact_Sheet_111820.pdf; New York State (2021). Ahead of Climate Week 2021, Governor Hochul Announces New Actions to Green New York's Transportation Sector and Reduce Climate-Impacting Emissions. https://www.governor.ny.gov/news/advance-climate-week2021-governor-hochul-announces-new-actions-make-new-yorks-transportation

the development and adoption of zero-emission technologies. Specific measures include:

1) Revision of the In-Use Off-Road Diesel-Fueled Fleets Regulation[8], which mandates the gradual phase-out of diesel machinery over 20 years old starting as early as 2028, while providing flexibility for fleets using zero-emission machinery.

2) A plan to require 100% zero-emission new forklifts by 2026, with a gradual phase-out of forklifts over 10 years old beginning in 2028.[9]

3) Incorporation of greenhouse gas emission standards, including potential CO_2, CH_4, and N_2O limits, in the development of stricter Tier 5 regulations. [10]

4) A proposal to establish zero-emission targets for manufacturers as early as 2031 to address the scarcity of zero-emission machinery and accelerate production and sales. [11]

5) Financial incentives through programs like the Clean Off-Road Equipment (CORE) program, providing direct economic support for zero-emission machinery. [12] CORE, the largest global investment program of its kind, allocated over $508 million from 2017 to 2023, with purchase subsidies of up to $500,000 per zero-emission machine.

ii.<u>*Establishing Emission standards*</u>

Emission standards are a common method to reduce pollutant emissions from non-road machinery. The EU Stage V emission standards for non-road machinery are currently the strictest in the world, requiring the use of particulate filters to comply. These standards have been adopted by the EU, India, and China. In North America, the Tier 4f emission standards remain in effect, which do not require particulate filters for compliance. California is considering proposing stricter Tier 5 standards, but there are no plans yet to mandate the use of particulate filters.

Although nearly all non-road mobile machinery relies on diesel fuel, no

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[8] California Air Resources Board (2020), Strategic Plan for Zero-Emission Off-Road Equipment. https://ww2.arb.ca.gov/sites/default/files/2020-11/ZEV_EO_Off-Road_Fact_Sheet_111820.pdf

[9] California Air Resources Board (2023), Zero-Emission Forklifts. https://ww2.arb.ca.gov/our-work/programs/zero-emission-forklifts

[10] California Air Resources Board (2022), Future Tier 5 Regulation Development, Greenhouse Gas (GHG) Reduction, and Emission Standards. https://ww2.arb.ca.gov/sites/default/files/2022-08/Capping%20Standards%20for%20Workgroup%20Meeting%2008082022%20V7%20Post%20Chris%20Revisions_ADA_07252022_%2802%29_SA_DL_JL.pdf

[11] California Air Resources Board (2023), Off-Road Mobile Machinery Regulation Development and Incentive Measures Hearing. https://ww2.arb.ca.gov/sites/default/files/2023-05/Off-road%20Listening%20Session_final_1.pdf

[12] Clean Off-Road Equipment (CORE) Incentive Program. https://californiacore.org

regulations have yet been implemented to address its climate impact. Non-road mobile machinery currently lacks standards for fuel consumption, carbon dioxide (CO_2), or greenhouse gas (GHG) emissions. However, California and China are considering introducing such requirements. Experience from road vehicle management shows that if standards are sufficiently strict and regulatory structures are well-designed, they can effectively promote the adoption of zero-emission technologies.

iii.*Establishing Low-Emission and Zero-Emission Zones*

Establishing Low-Emission Zones (LEZs) and Zero-Emission Zones (ZEZs) initially targeted pollution from road vehicles but has now expanded to include construction sites in urban areas. LEZ and ZEZ requirements vary by city. Typically, LEZs set minimum emission standards for vehicles and machinery operating within the zone, while ZEZs only allow vehicles and machinery with zero exhaust emissions.

London, UK, launched the world's first non-road LEZ and plans to upgrade it to a ZEZ by 2040. Oslo[13], Norway, piloted the world's first zero-emission construction site. [14]Copenhagen, Denmark, established its first zero-emission construction site in August 2020. Other European cities, including Helsinki (Finland), Vantaa (Finland), Rotterdam (Netherlands), Amsterdam (Netherlands), and Vienna (Austria), are planning demonstration projects for zero-emission construction sites. Barcelona, [15]Spain, has also initiated a small pilot project using electric machinery at a construction site in the city. [16]

[13] London Mayor, Non-Road Mobile Machinery (NRMM). https://www.london.gov.uk/programmes-and-strategies/environment-and-climate-change/pollution-and-air-quality/nrmm

[14] Oslo Climate Agency (2020), Quiet, Clean, and Green: Exploring Oslo's Zero-Emission Construction Sites. https://eurocities.eu/stories/quiet-clean-and-green-discover-oslos-zero-emissions-construction-site/

[15] European Commission, Big Buyers Working Together. https://bigbuyers.eu/fileadmin/user_upload/Materials/BBCE_ZEMCONs_Kick-off_12.04.21.pdf

[16] European Commission (2023), Webinar on How to Procure "Zero-Emission Construction Sites". https://public-buyers-community.ec.europa.eu/resources/webinar-how-procure-zero-emission-construction-site

Norway's Oslo Zero-Emission Zone for Construction Machinery.

Oslo's first zero-emission zone for construction machinery was the Olav V Gate pedestrian zone renovation project, launched in September 2019. This project marked a significant step in Oslo's efforts to achieve its 2030 greenhouse gas reduction target of a 95% citywide emission cut. Construction machinery is estimated to account for about 30% of Oslo's transport-related greenhouse gas emissions. In addition to the pedestrian zone project, other initiatives, including school and sports facility projects, will also use zero-emission construction machinery. By 2025, all municipal construction sites in Oslo are expected to be fossil fuel-free, with all other construction projects following suit by 2030. Oslo's climate project budget is integrated with its city fiscal budget, prioritizing climate-friendly initiatives.

Olav V Gate is globally recognized as the first zero-emission zone for construction machinery. Tender documents for the project required all machinery and equipment to use alternative fuels instead of fossil fuels. The project utilized three electric excavators and other electric machinery supplied by NASTA, Hitachi's Scandinavian dealer, and Pon Cat, Caterpillar's Norwegian dealer. Both companies are advancing the electrification of their product lines. The zero-emission zone pilot also included investments in charging infrastructure.

The Olav V Gate pilot project saved a total of 35,000 liters of diesel, equivalent to nearly 93 tons of CO_2 emissions. [17] The project cost $7.2 million, higher than the $6.6 million estimated for a traditional project, primarily due to the current scarcity and high cost of electric machinery.

iv.*Restricting Diesel Machinery*

Emissions from diesel-powered machinery can pose significant health risks in certain application scenarios where ventilation may be limited. Although most countries and regions do not prohibit the use of diesel engines in these specific scenarios, they may impose health and safety management requirements or restrictions and additional conditions on the use of diesel machinery. In such scenarios, zero-emission machinery may already offer better cost-effectiveness compared to diesel machinery. Many countries and regions, including European nations, California, Canada, Japan, and China, have implemented similar restrictions for road vehicles, but no comparable regulations have been observed in the non-road sector.

[17] Reuters (2020), Norway's Oslo "Zero-Emission" Construction Site Ditches Diesel Engines. https://www.cbc.ca/news/science/ zero-emissions-building-site-1.584330

v.*Noise Limitations*

Noise restrictions can limit the operating hours of construction machinery, whereas electric machinery, with relatively lower noise levels, can operate for longer periods in many scenarios. In Europe, the *Outdoor Machinery Directive* mandates noise reduction for machinery regardless of the power source. [18]In China, the use of low-noise construction equipment is encouraged, with many recommended models being electric machinery.[19]

(2) Financial and Tax Measures

Financial and tax measures mainly include direct economic incentives, preferential loans, funding support, infrastructure investments, and tax benefits.

i.*Direct Economic Incentives*

Direct financial incentives for zero-emission machinery are primarily focused on the construction industry to reduce costs, and such measures are commonly used in Europe and North America. In addition to the California CORE subsidy program mentioned earlier, the Netherlands has a national incentive scheme called the Subsidy Scheme for Clean and Emission-Free Construction Equipment (SSEB). This program will provide a total of €270 million in funding by the end of 2030, offering subsidies of up to 50% of the purchase price for each piece of machinery. [20]The Netherlands is currently the only European country to implement direct financial and tax incentives.

ii.*Preferential Loans*

Financing can facilitate the purchase of zero-emission machinery, especially for small fleets and operators. However, financial companies remain uncertain about the residual value and operational costs of these new electric machines, making them reluctant to provide financing. Currently, only Oslo offers low-interest financing for zero-emission machinery, but this program has limited scope and applicability, focusing primarily on public procurement.

At the EU level, supported by the new InvestEU program, the European

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[18] European Commission, Directive on Noise from Outdoor Equipment. https://single-market-economy.ec.europa.eu/sectors/mechanical-engineering/noise-emission-outdoor-equipment_en#:~:text=The%20Outdoor%20Noise%20Directive%202000, or%20in%20 公园%20 和%20 花园

[19] Ministry of Industry and Information Technology of China (2023), Guidance Catalogue of Low-Noise Construction Equipment (First Batch). https://www.mee.gov.cn/xxgk2018/xxgk/xxgk10/202305/t20230523_1030831.html

[20] RVO, the Netherlands Enterprise Agency (2023), Subsidy for Clean and Zero Emission Construction Equipment (SSEB). https://business.gov.nl/subsidy/clean-andzero-emission-construction-equipment-sseb/

Investment Bank (EIB) has invested in the machinery fleet of French leasing company Loxam. The funding is intended to replace fossil-fuel-based machinery with electrified equipment. Loxam aims to reduce indirect emissions by 30% and direct emissions by 50% by 2030. The total investment budget is €400 million, with €70 million invested in 2021[21].

Netherlands-based rental company Collé Rental & Sales also received a €50 million loan from the EIB to purchase electric machinery. This investment is guaranteed by the European Fund for Strategic Investments, part of Europe's initiative to promote low-carbon investments[22].

iii.*Providing Project Funding (including pilot project)*

National and local governments are funding pilot projects for zero-emission non-road machinery, and many manufacturers have also initiated pilot projects to test zero-emission equipment. In Scandinavia, Skanska and Volvo funded a pilot project applying zero- and low-emission machinery at a quarry. Leading small equipment supplier Wacker Neuson conducted pilot applications of zero-emission machinery in Stuttgart and Barcelona. [23]The EU's LIFE program is testing the application of zero-emission power generation equipment by replacing generators at 12 construction sites across Europe.[24]

Volvo's Zero-Emission Pilot Projects

In 2018, Volvo, in partnership with Skanska, created the world's first zero-emission quarry as a research pilot project. [25] In October 2015, Volvo collaborated with Skanska, the Swedish Energy Agency, and two Swedish universities (Linköping University and Mälardalen University) to launch a pilot project with a total investment of 203 million SEK (approximately $22.34

[21] European Investment Bank (2022), France: InvestEU-Loxam Receives EUR 130 Million Loan from the European Investment Bank to Support Its Energy Transition. https://www.eib.org/en/press/all/2022-376-investeu-in-france-loxam-receives-eur130-million-loan-fromthe-eib-to-support-its-能量转换

[22] M.Paul (2022), Collé Rental gets charged with €50 million from EIB to speed up electrification of rental machinery. https://tech.eu/2022/08/22/dutch-company-colle-rental-sales-receives-eur50-million-from-eib-for-further-electrification-of-rental-machinery/

[23] Wacker Neuson Magazine (2022), Electric construction machines impress in practical test in Stuttgart inner city. https://magazine.wackerneuson.com/en/electric-construction-machines-impress-in-practical-test-in-stuttgart-inner-city/

[24] European Climate, Infrastructure and Environment Executive Agency (2022), Zero-Emission Battery Power Supply for Cleaner Air. https://cinea.ec.europa.eu/newsevents/news/zero-emission-battery-power-supply-cleaner-air-2022-04-20_en

[25] Press Release (2018), World's First "Zero-Emission" Quarry Begins Testing. https://www.volvoce.com/global/en/news-and-events/news-and-stories/2022/volvo-ce-partners-on-swedens-largest-fossil-free-worksite

million), known as "Electric Site." Volvo was responsible for developing the machinery and systems, Skanska provided logistics solutions, applications, and site knowledge, the Swedish Energy Agency funded the project, and the two universities conducted relevant research.

The feasibility study for Electric Site was conducted at Skanska's second-largest quarry, the Vikan Kross quarry, with a 10-week testing phase. The goal was to electrify the transportation process from excavation through primary crushing and secondary crushing at the quarry. The pilot used three main types of concept machinery:

Transportation Equipment: Eight fully automated electric HX02 dump trucks (prototype) were used to transport materials from the primary dynamic crusher to the secondary static crusher. The dump trucks were equipped with lithium batteries, powered by two electric motors, with the hydraulic system driven by an additional electric motor.

Excavation Equipment: The primary crusher on site was loaded by a 70-ton dual-powered, cable-connected EX01 excavator prototype. When connected to the power source, the EX01 automatically switched to electric mode; if not connected, it operated in diesel mode.

Loading Equipment: The pilot project also used Volvo's SE LX1 hybrid wheel loader prototype, which achieved a 50% improvement in fuel efficiency compared to traditional machinery of the same class, significantly reducing emissions and noise pollution.

The test data showed that using zero-emission machinery resulted in a 98% reduction in carbon emissions, a 70% reduction in energy costs, and a 40% reduction in operational costs. The pilot project demonstrated that zero-emission machinery could improve energy efficiency by ten times, achieving zero accidents, zero unplanned downtime, and zero direct emissions. With zero-emission machinery in use, total costs could be reduced by 25%.

iv.*Investments on Infrastructure*

So far, there has been limited investment in infrastructure for zero-emission machinery, as such equipment is rarely deployed. However, Oslo included infrastructure investment in its zero-emission zone pilot project. Additionally, in several port projects, including those at the Port of Valencia, Port of Los Angeles, and Port of Long Beach, infrastructure investments have been made to support non-road mobile machinery such as terminal tractors, straddle carriers, and container handling machines. [26]

v.*Tax benefits*

Imposing carbon taxes on fuel increases the relative cost of using diesel fuel compared to electricity. Currently, carbon taxes are still low but are expanding across Europe, and carbon allowances can be traded at the EU level. In the future, carbon tax policies may extend to cover emissions from construction machinery.

In some countries and regions, fuel taxes for non-road machinery are lower than for road vehicles. Increasing diesel taxes or removing diesel subsidies would lower operational and energy costs for zero-emission machinery, thus supporting their development and application. For example, in the UK, construction machinery can use red diesel, which is taxed at a lower rate, but after April 2022, only agricultural machinery is allowed to use this type of diesel. As a result, diesel-powered construction machinery will face higher fuel costs. France has also gradually phased out the diesel tax reduction for non-road machinery since 2019. [27]These changes will directly impact end users. For rental companies, choosing machinery with lower fuel consumption or zero emissions will bring greater benefits, as the lowest-cost machinery may not always be the best choice.

Many markets have incentives for investing in fixed equipment, but this is currently not limited to zero-emission machinery. For example, France's corporate tax incentives cover electric, natural gas, hydrogen, and hybrid machinery.

(3) Market Mechanism and industry Strategies

In addition to implementing incentive policies and providing financial and tax support, some cities and regions have also made significant efforts at the market mechanism and industry strategy level, such as:

i.*Procurement Policies*

The "Big Buyers Initiative" was launched by cities including Amsterdam, Brussels, Budapest, Copenhagen, Helsinki, Lisbon, Oslo, Trondheim, and Vienna to promote the establishment of zero-emission zones for construction machinery.

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[26] World Ports Sustainability Program (2019), Port of Valencia – H2Ports / Fuel Cells and Hydrogen in Ports. https://sustainableworldports.org/project/port-of-valencia-h2ports/

[27] Deloitte Touche Tohmatsu Limited (2019), The 2020 Finance Bill Includes Measures to Reduce Corporate Tax Rates. https://www.taxahand.com/article/12284/France/2019/2020-finance-bill-contains-measures-on-corporate-tax-rate-reduction

Some of the funding for this initiative is provided by the European Union[28].

ii.*Corporate Social Responsibility (CSR) and Environmental, Social, and Governance (ESG) Strategies*

Leading construction and mining companies are currently incorporating emission reduction into their corporate social responsibility (CSR) and environmental, social, and governance (ESG) strategies to drive low-carbon development. For example, Royal BAM in the Netherlands, in partnership with others, developed an electric asphalt paver. Lendlease in France used an electric excavator in the Manchester Town Hall renovation project as a demonstration for achieving its zero-carbon goal by 2024. Sunbelt Rentals (Ashtead) [29]in the UK and North America purchased a fleet of small electric excavators and two-thirds of the first batch of electric loaders [30] jointly developed and produced by the company and Doosan Bobcat (a non-road mobile machinery manufacturer).

Many mining companies in Australia and South America are expected to launch more projects like the Western Australian mining zero-emission initiative. [31] Manufacturers are also conducting pilot projects in this field; Komatsu established the Komatsu Greenhouse Gas Alliance[32], and another broader organization called the "Innovation Responsibility Alliance" has also been formed[33].

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[28] European Commission, Big Buyers Working Together. https://bigbuyers.eu/fileadmin/user_upload/Materials/Final_Press_Release_Statement_of_Demand_BBI_ZEMCONs.pdf

[29] Lendlease (2021), Using electrified plant to cut carbon emissions at Manchester Town Hall. https://www.lendlease.com/au/insights/using-electrified-plant-to-cut-carbon-emissions-at-manchester-town-hall/?utm_source=url-redirect&utm_medium=www-lendlease-com_better-places_using-electrified-plant-to-cut-carbon-emissions-atmanchester-town-hall

[30]Ashtead Group (2022), DRIVING REAL CULTURAL CHANGE - Sustainability Report. https://www.ashtead-group.com/files/downloads/reports/2022/Ashtead_AR22_Responsible_Business.pdf

[31] Minerals Research Institute of Western Australia (2023), Net-Zero Emission Mining. https://www.mriwa.wa.gov.au/minerals-researchadvancing-western-australia/focus-areas/net-zero-emission-mining/

[32] Komatsu (2021), Komatsu announces collaborative customer alliance to advance zero-emission equipment solutions -New offerings to leverage electrification for next generation- https://www.komatsu.jp/en/newsroom/2021/20210802

[33] Charge On Innovation Challenge. https://chargeoninnovation.com/

4. What is the development status of non-road mobile machinery in China?

Most of China's leading construction machinery manufacturers have invested in the research and development of new energy machinery, with products covering a wide range of equipment such as forklifts, excavators, loaders, bulldozers, aerial work platforms, and cranes. Driven by China's technological advantages in new energy vehicles, the development and application of new energy construction machinery in China are internationally leading.

Among various construction machinery types, forklifts and aerial work platforms have the highest electrification rates. In 2022 and 2023, the electrification rates of new forklift sales in China were 64.4% and 67.9%, respectively, with electric forklifts covering all tonnage ranges from small to large. The electrification rate of aerial work platforms has exceeded 90%.

In recent years, the sales of electric loaders have been rapidly increasing, with 1,160 units sold in 2022 and 3,595 units sold in 2023, achieving electrification rates of 0.9% and 3.5%, respectively. Other construction machinery types, such as excavators, bulldozers, and road rollers, have also seen electric products enter the market for application.

(1) Construction Machinery

China's construction machinery sector is diverse, primarily consisting of forklifts, excavators, loaders, road rollers, bulldozers, graders, and pavers. From 2017 to 2023, total sales of construction machinery increased from 756,000 units to 1.496 million units[34], with an average annual growth rate of 13.1%, as shown in Figure 4. Specifically, forklift sales grew from 497,000 units to 1.174 million units, with an average annual increase of 13.0%; excavator sales rose from 140,000 units to 195,000 units, with an average annual increase of 9.2%; loader sales increased from 89,000 units to 104,000 units, with an average annual increase of 3.7%; road roller sales decreased from 17,000 units to 14,000 units, with an average annual decrease of 2.7%; bulldozer sales increased from 6,000 units to 7,000 units, with an average annual increase of 4.9%; grader sales grew from 5,000 units to 7,000 units, with an average annual increase of 8.8%; paver sales decreased from 2,000 units to 1,000 units, with an average annual decrease of 8.8%.

Forklifts are currently the construction machinery type with the highest electrification rate. From 2017 to 2023, sales of pure electric forklifts increased

[34] Data source: China Construction Machinery Association

from 204,000 units to 797,000 units, with an average annual growth rate of 27.1%, as shown in Figure 5. The share of pure electric forklifts increased from 41.0% to 67.9%, a rise of 26.9 percentage points.

Most Chinese companies have also invested in the research and development of large electric construction machinery, including excavators, loaders, mobile cranes, and terminal tractors. Among these, electric loader products are mainly focused on the most common 5-ton models, with relatively mature technology. Hydrogen fuel cell non-road mobile machinery is also under research and demonstration application in China.

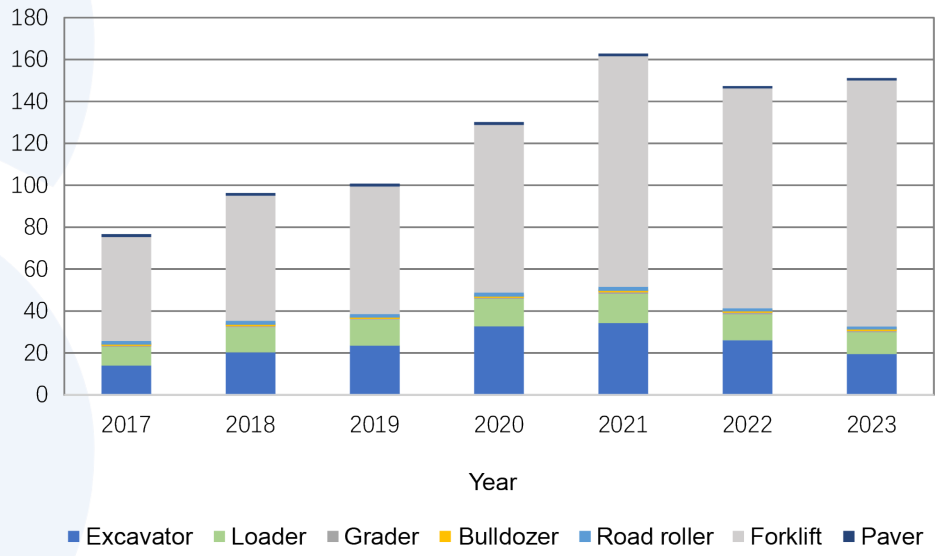

Figure 4 Sales Volume of Major Construction Machinery in China

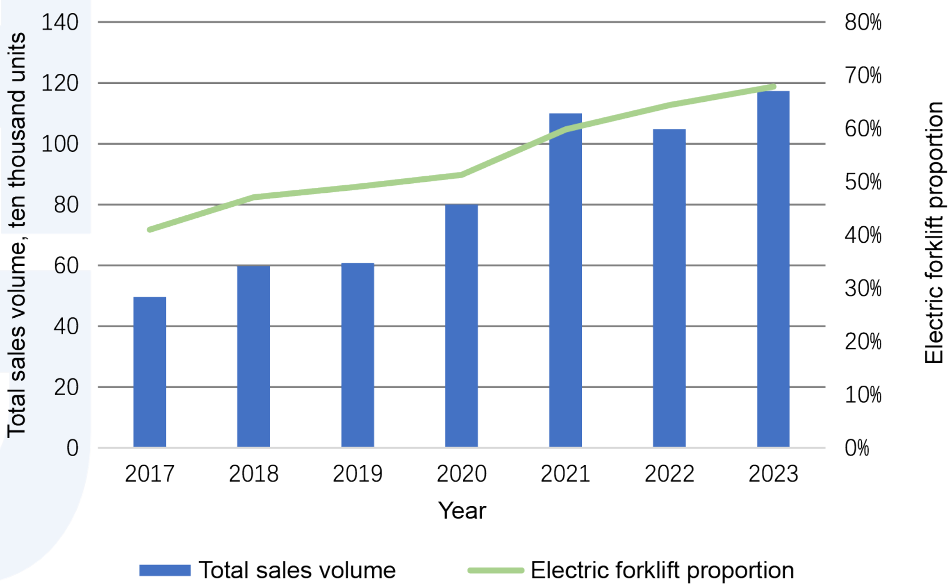

Figure 5 Sales Volume and Electrification Rate of Forklifts in China

According to the literature reports[35] and estimates based on sales data from the China Construction Machinery Industry Association and machinery lifecycle, by the end of 2022, the total number of construction machinery in China was approximately 8.1 million units. The composition of the main construction machinery types is shown in Figure 6. The China Construction Machinery Industry Association reported that the sales of construction machinery in China for 2023 were 923,000 units, as shown.

Based on the method outlined in the literature, it is roughly estimated that the total number of construction machinery in China is approximately 9 million units.

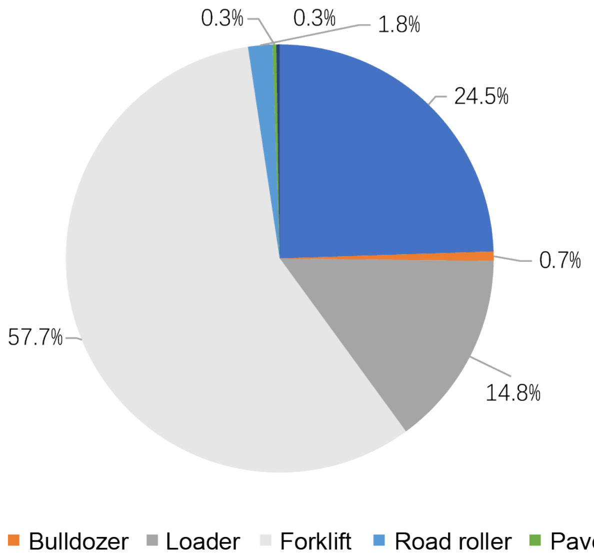

Figure 6 Composition of China's Construction Machinery Stock in 2022

[35] HUANG Zhihui, HE Zhuoshi, JI Liang, WANG Yunjing, WANG Hongli, WANG Junfang, YIN Hang, DING Yan. Status Assessment of Carbon Dioxide and Pollutant Emissions of Construction Machineries in China [J]. Research of Environmental Sciences, 2023(10):85-94.

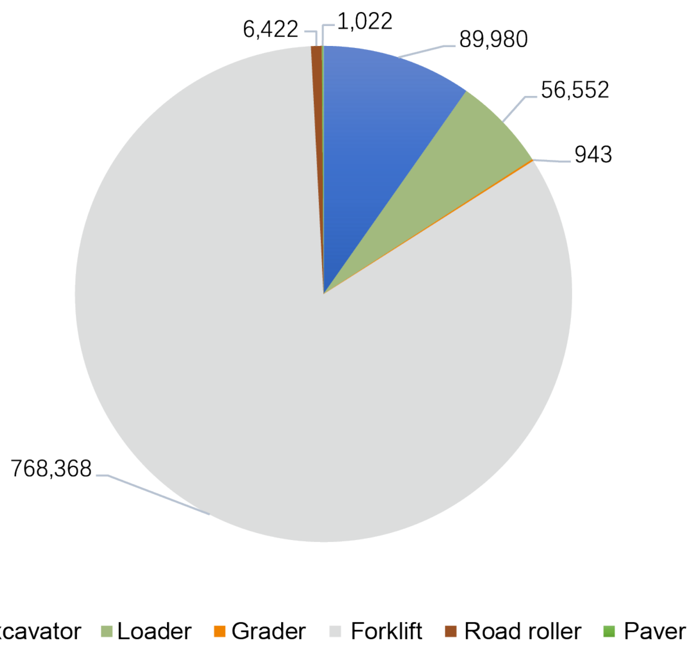

Figure 7 Sales Volume of China's Construction Machinery in 2023

(2) Agricultural Machinery

The main types of agricultural machinery include large, medium, and small tractors, harvesting machinery (for wheat, corn, and rice), irrigation and drainage machinery, etc. In recent years, there has been a clear trend toward the larger size of agricultural machinery, with the production of large tractors increasing, while the production of small tractors is rapidly declining. In 2022, the total production of tractors was 551,000 units, a decrease of 3.2% compared to the previous year. From 2017 to 2023, tractor production dropped from 1.414 million units to 551,000 units[36], with an average annual decrease of 10.2%. Among these, the production of large tractors increased from 51,000 units to 109,000 units, with an average annual growth rate of 17.5%; the production of medium-sized tractors decreased from 367,000 units to 273,000 units, with an average annual decrease of 1.8%; and the production of small tractors decreased from 996,000 units to 169,000 units, with an average annual decrease of 19.3%.

[36] Data Source: China Association of Agricultural Machinery Manufacturers

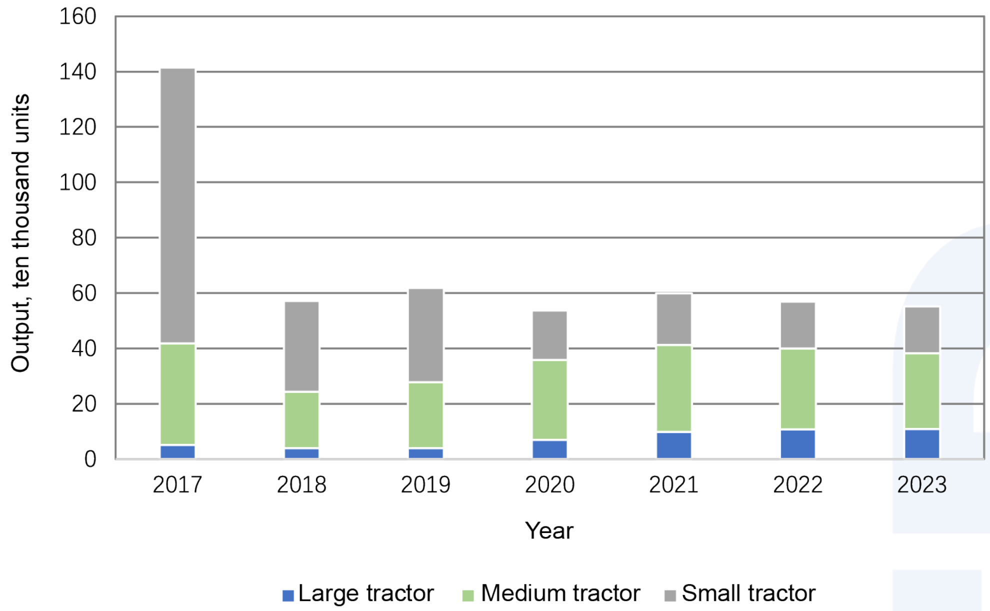

Figure 8 Production Volume of Major Agricultural Machinery in China

According to the *China Statistical Yearbook*, the changes in the total power and ownership of major agricultural machinery types in China since 2012 are shown in Figure 9. Starting from 2016, agricultural transport vehicles are no longer included. From 2017 to 2022, the comprehensive mechanization rate for crop farming (including plowing, planting, and harvesting) increased from 66% to 73%, a rise of 7 percentage points. The total power of agricultural machinery increased from 990 million kW[37] to 1.1 billion kW, with an average annual growth rate of 2.3%.

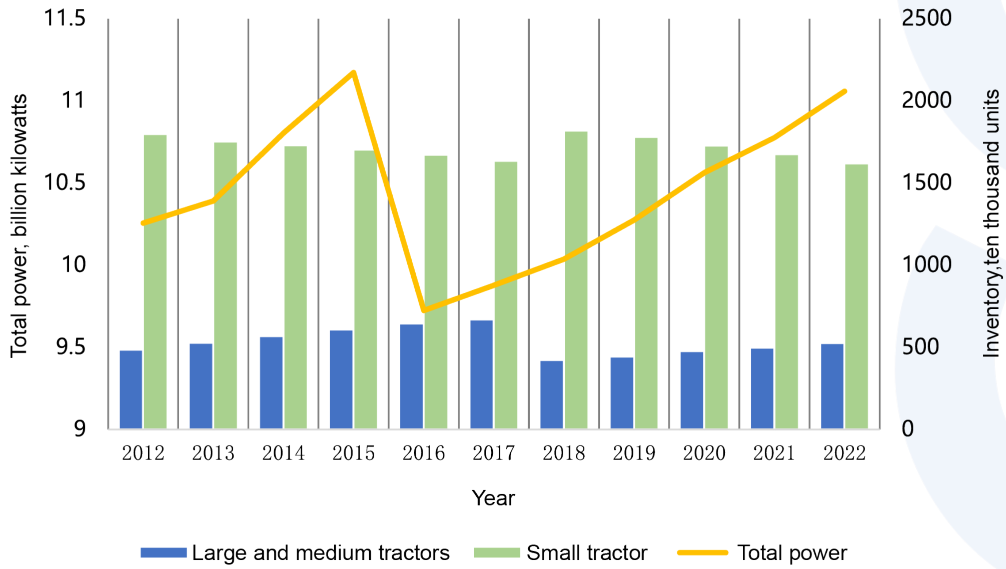

Figure 9 Total Power and Stock of Major Agricultural Machinery and the Ownership of Major Machine Types in China

[37] Data Source: Ministry of Agriculture and Rural Affairs and National Bureau of Statistics

5. What is the pollution emission level of non-road mobile machinery in China?

According to the *China Mobile Source Environmental Management Annual Report 2023*, in 2022, the emissions of hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) from non-road mobile machinery were 311,000 tons, 3,002,000 tons, and 163,000 tons, respectively, accounting for 13.3%, 30.0%, and 57.1% of the total emissions from mobile sources. The pollutant emissions from construction machinery and agricultural machinery are as follows.

(1) Construction machinery

In 2022, the emissions from construction machinery in China were as follows: excavators emitted 40,000 tons of HC, 503,000 tons of NOx, and 38,000 tons of PM; bulldozers emitted 3,000 tons of HC, 17,000 tons of NOx, and 1,000 tons of PM; loaders emitted 45,000 tons of HC, 540,000 tons of NOx, and 25,000 tons of PM; forklifts emitted 11,000 tons of HC, 198,000 tons of NOx, and 7,000 tons of PM; road rollers emitted 5,000 tons of HC, 75,000 tons of NOx, and 1,000 tons of PM; pavers emitted 1,000 tons of HC, 8,000 tons of NOx, and 400 tons of PM; graders emitted 1,000 tons of HC, 9,000 tons of NOx, and 200 tons of PM. The emission distribution by machinery type is shown in Figures 10 to 12.

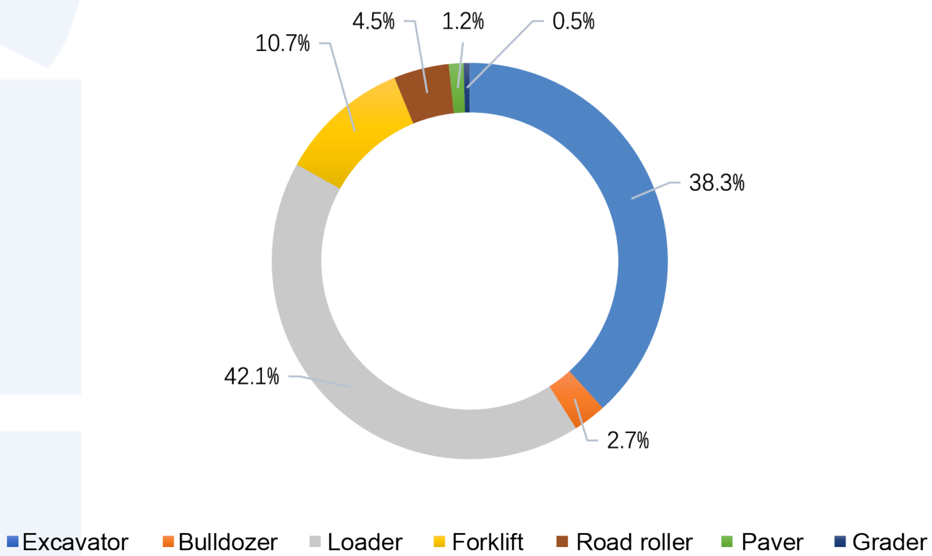

Figure 10 Composition of HC Emissions from China's Construction Machinery by Machinery Type

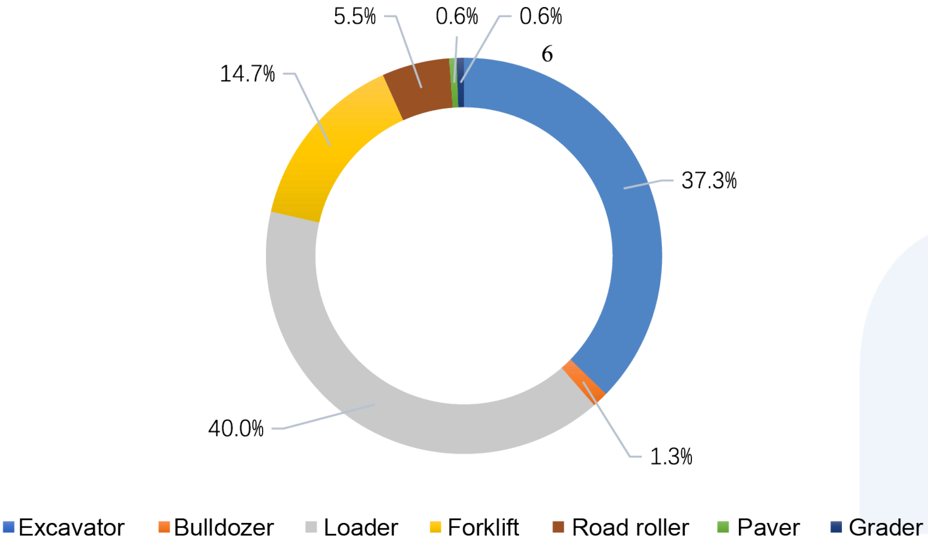

Figure 11 Composition of NOx Emissions from China's Construction Machinery by Machinery Type

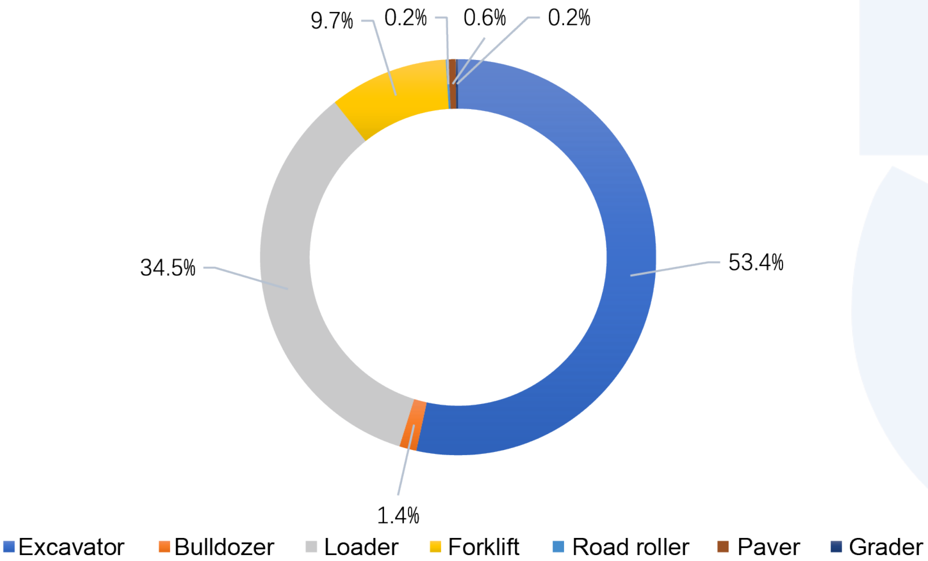

Figure 12 Composition of PM Emissions from China's Construction Machinery by Machinery Type

(2) Agricultural Machinery

In 2022, the emissions from agricultural machinery in China were as follows: large and medium-sized tractors emitted 59,000 tons of HC, 587,000 tons of NOx, and 11,000 tons of PM; small tractors emitted 39,000 tons of HC, 356,000 tons of NOx, and 8,000 tons of PM; combine harvesters emitted 8,000 tons of HC, 99,000 tons of NOx, and 4,000 tons of PM; fishery machinery emitted 6,000 tons of HC, 37,000 tons of NOx, and 4,000 tons of PM; other agricultural machinery emitted 93,000 tons of HC, 571,000 tons of NOx, and 65,000 tons of PM. The emission distribution by machinery type is shown in Figures 13 to 15.

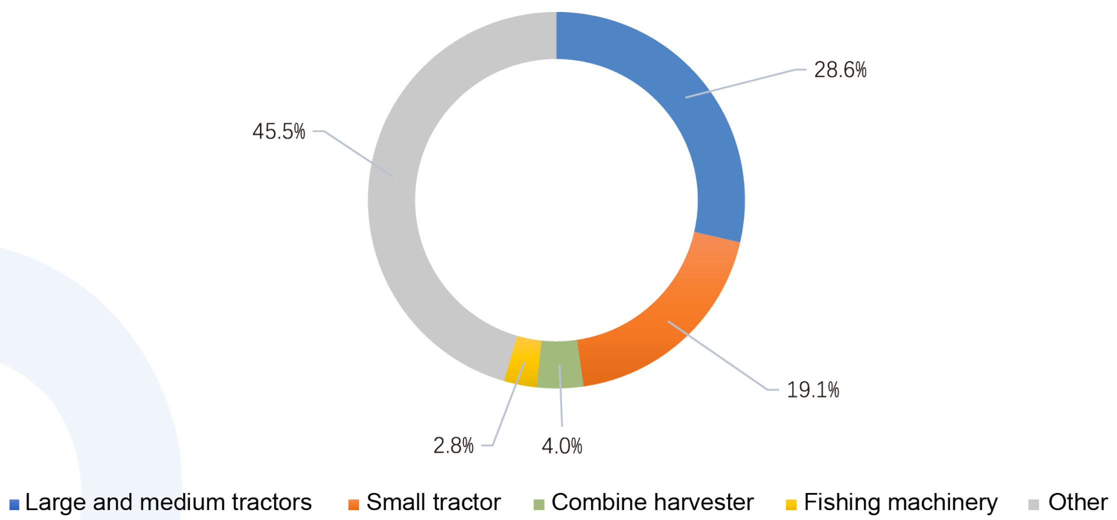

Figure 13 Composition of HC Emissions from China's Agricultural Machinery by Machinery Type

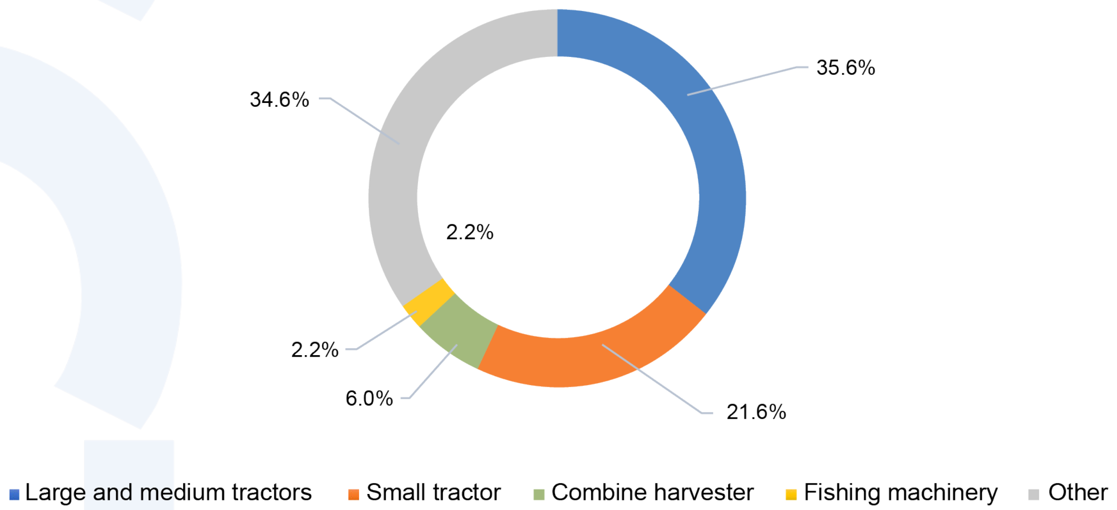

Figure 14 Composition of NOx Emissions from China's Agricultural Machinery by Machinery Type

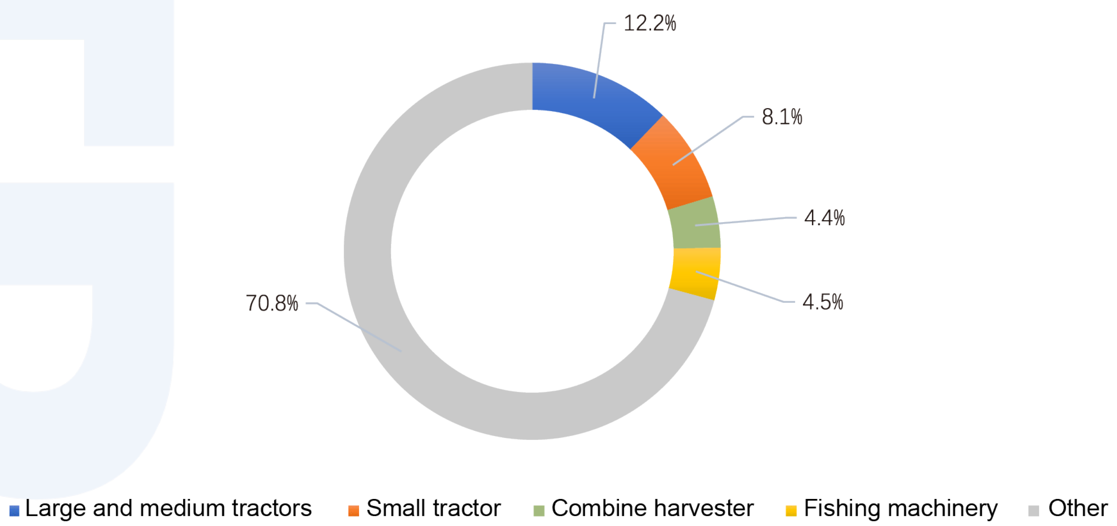

Figure 15 Composition of PM Emissions from China's Agricultural Machinery by Machinery Type

6. What relevant laws, regulations, and policies have been issued for non-road mobile machinery?

(1) Legal regulations

The main legal basis for the environmental management of non-road mobile machinery currently includes the *Air Pollution Prevention and Control Law*, provincial and municipal air pollution control regulations, and specialized regulations on mobile sources/non-road mobile machinery, all of which implement the *Air Pollution Prevention and Control Law* and improve the legal protections for existing regulatory measures. Other related laws and regulations, such as the *Energy Conservation Law*, also provide requirements or stipulations regarding the emissions and regulations of non-road mobile machinery in some areas.

The *Air Pollution Prevention and Control Law* mainly addresses non-road mobile machinery in the following areas:

1) **Lifecycle Stages**: The law specifies the requirements for non-road mobile machinery across various lifecycle stages, including production, import, sale, usage, and scrapping. It also defines the responsibilities of companies and users at each stage. At the production, import, and sale stages, non-road mobile machinery must comply with emission standards, and new machinery is required to undergo emissions testing with the results made publicly available. During the usage stage, the government encourages and supports the early retirement of high-emission non-road mobile machinery.

2) **Regulatory Authorities**: The law assigns responsibilities to various departments such as local governments, ecological and environmental departments, transportation, housing and urban construction, agriculture, water administration, industry, quality supervision, and business administration. Local governments can designate areas where high-emission non-road mobile machinery is prohibited based on air quality. Relevant departments such as transportation, housing and urban construction, and agriculture mainly supervise emissions during the usage in-use phase, while quality supervision and business administration focus on emissions control during the production and design phases. Ecological and environmental departments are responsible for supervising machinery at the production, sales, and in-use phases.

3) **Technical Requirements for Emissions**: The law outlines regulatory requirements for fuels, lubricants, nitrogen oxide reducers, oil additives, and pollution control devices used in non-road mobile machinery.

The *Energy Conservation Law* states that relevant authorities in agriculture, science, and other sectors should support and promote energy-saving technologies and products in agricultural production, processing, and storage, encouraging the updating and elimination of high-energy-consuming agricultural machinery.

The *Circular Economy Promotion Law* stipulates that county-level and higher governments, along with agriculture departments, should promote energy savings in agricultural machinery, prioritize ecological agriculture development, and support enterprises in remanufacturing vehicle components, construction machinery, machine tools, and tire refurbishment.

The *Agricultural Mechanization Promotion Law* bans the production and sale of agricultural machinery that does not meet national technical standards. The central and provincial governments should allocate special funds to subsidize farmers and agricultural organizations for purchasing advanced agricultural machinery that is supported and promoted by the state. These funds must be used transparently and effectively, with subsidies distributed directly to farmers or through low-interest loans to support purchasing machinery.

The *Road Traffic Safety Law* specifies that tractors, wheeled special machinery, and other vehicles with a maximum speed of less than 70 kilometers per hour are prohibited from entering highways. For tractors on public roads, the agricultural (agricultural machinery) department exercises the authority of public security traffic management to manage registration, annual inspections, and driver licensing.

To facilitate the implementation of the *Air Pollution Prevention and Control Law* and the *Diesel Truck Pollution Control Campaign*, most provinces and cities have included related provisions when revising local air pollution regulations. Four provinces, including Anhui, Heilongjiang, Inner Mongolia, and Xinjiang, do not include non-road mobile machinery-related content in their air regulations. However, 27 provincial air regulations include provisions for non-road mobile machinery, with 13 of them specifying high-emission non-road mobile machinery prohibition zones, 9 of which clearly state penalties. Eight provinces (including Beijing, Fujian, Guangdong, and Chongqing) explicitly require in-use non-road mobile machinery to meet emission standards. Chongqing's air regulation includes content on registration and coding.

In addition to the provincial air pollution regulations, more than 80 prefecture-level cities have formulated their own air pollution control regulations, about half of which address high-emission non-road mobile machinery prohibition zones, coding, and in-use machinery emission compliance.

(2) Related regulations

Related policies mainly include national macro policies, air pollutant and greenhouse gas reduction policies, industry and economic development policies, as well as local supporting policies formulated by local governments to implement national policies.

1) National macro Policies

In 2021, the Central Committee of the Communist Party of China and the State Council issued the *Opinions on Fully, Accurately, and Comprehensively Implementing the New Development Philosophy and Achieving Carbon Peaking and Carbon Neutrality*. In the section on key tasks for deeply adjusting the industrial structure, it emphasized the vigorous development of green and low-carbon industries and explicitly mentioned the development of new energy vehicles, although it did not specifically mention machinery. Considering that the construction machinery industry is a crucial pillar of China's national economic development, the industry also needs to vigorously transition towards green and low-carbon development.

In 2023, the Central Committee of the Communist Party of China and the State Council issued the *Opinions on Fully Promoting the Construction of a Beautiful China*. In the section on accelerating the green transformation of development models and promoting green and low-carbon development in key areas, it called for the vigorous promotion of traditional industry equipment upgrades to achieve green and low-carbon transformation, and the implementation of clean production level enhancement projects. It also encouraged the green transformation of railway stations, civil airports, port terminals, logistics parks, and the electrification of railways, and promoted the large-scale application of ultra-low and near-zero emission vehicles and the clean and low-carbon application of non-road mobile machinery.

2) Air Pollutant and Greenhouse Gas Reduction policies

In 2018, the State Council, the Ministry of Ecology and Environment, and related ministries issued a series of policies, including the *Three-Year Action Plan to Win the Battle for Blue Skies*, the *Action Plan for Diesel Truck Pollution Control*, and the *Pollution Prevention and Control Technical Policies for Non-Road Mobile Machinery*, to comprehensively promote pollution control and the clean development of non-road mobile machinery.

Starting in 2019, the government introduced a series of policies to drive emissions control and the transition to new energy in non-road mobile machinery. In 2019, the Ministry of Ecology and Environment issued the *Guiding*

Opinions on Strengthening the Response to Severe Pollution Weather and Consolidating Emergency Emission Reduction Measures, requiring companies to increase the proportion of non-road mobile machinery that meets the National III or higher emission standards, or those powered by new energy. In 2021, the Central Committee of the Communist Party of China and the State Council released the *Opinions on Deepening the Battle Against Pollution*, which called for continued progress in diesel truck pollution control and the implementation of clean diesel vehicle actions.

In 2022, the State Council issued the *14th Five-Year Comprehensive Energy Conservation and Emissions Reduction Work Plan*, which called for the improvement of pollution prevention and control management measures for non-road mobile machinery, the full implementation of National IV emission standards, and the requirement that imported machinery comply with domestic emission standards. In the same year, the *Implementation Plan for Coordinated Pollution Reduction and Carbon Reduction* proposed the orderly promotion of the transition of non-road mobile machinery to new energy and clean energy power. Additionally, the *Action Plan for Diesel Truck Pollution Control* emphasized comprehensive governance measures for non-road mobile machinery, including promoting the implementation of Stage IV emission standards, accelerating the replacement and elimination of old machinery, and strengthening emissions monitoring to ensure that non-compliant machinery cannot be used in control areas.

In 2023, the State Council issued the *Air Quality Continuous Improvement Action Plan*, which further increased efforts for comprehensive governance of non-road mobile sources. The plan required accelerating the replacement of old machinery with new energy vehicles in places such as railway cargo yards, logistics parks, and ports, aiming to basically eliminate non-road mobile machinery that does not meet Stage I emission standards by 2025. This series of policies has laid a solid foundation for the green transition of non-road mobile machinery in China.

3) <u>Industry and Economic Development Policies</u>

In 2021, the China Construction Machinery Industry Association, commissioned by the Equipment Industry Department of the Ministry of Industry and Information Technology, released the "*14th Five-Year*" *Development Plan for the Construction Machinery Industry*. This plan emphasized key support for the development of clean and low-carbon technologies, including actively implementing National IV emission standards, accelerating the research and development of green and low-carbon products, and overcoming key technologies for electric construction machinery.

In 2024, the State Council issued the *Action Plan for Promoting Large-Scale Equipment Renewal and Consumer Goods Trade-In*. This plan proposed accelerating the equipment renewal in the construction and municipal infrastructure sectors. Subsequently, the Ministry of Housing and Urban-Rural Development issued the *Implementation Plan for Advancing the Renewal of Construction and Municipal Infrastructure Equipment*, which clarified the requirements and supporting measures for the elimination and renewal of construction equipment, providing policy support for the replacement of old machinery from a high-quality development perspective.

7. What major environmental regulatory measures has China taken regarding the pollution emissions of non-road machinery?

After the revision of the Air Pollution Prevention and Control Law in 2015, the environmental regulatory system for non-road mobile machinery gradually improved, and various regulatory frameworks were established. Starting in 2016, some cities began designating high-emission non-road mobile machinery prohibition zones. On July 1, 2017, non-road mobile machinery started implementing environmental information disclosure. After the release of the Action Plan for Diesel Truck Pollution Control in 2018, non-road mobile machinery began to be subject to coding and registration. Currently, these regulatory systems are operating stably. The specific regulatory measures mainly include environmental information disclosure, coding and registration, high-emission non-road mobile machinery prohibition zones, and the elimination and scrapping of old machinery.

(1) Environmental Information Disclosure

In 2016, the Ministry of Environmental Protection issued the *Announcement on the Public Disclosure of Environmental Protection Information for Motor Vehicles and Non-Road Mobile Machinery* (National Environmental Protection Regulation [2016] No. 3), which required that, starting from July 1, 2017, manufacturers and importers of non-road mobile machinery must publicly disclose the environmental protection information of newly produced or imported machinery according to specified timelines and methods. Currently, non-road mobile machinery companies are required to disclose information about machinery models and individual machines. Since 2017, the number of disclosed non-road mobile machinery model information is shown in Figure 16, with 13,507 models disclosed in 2023.

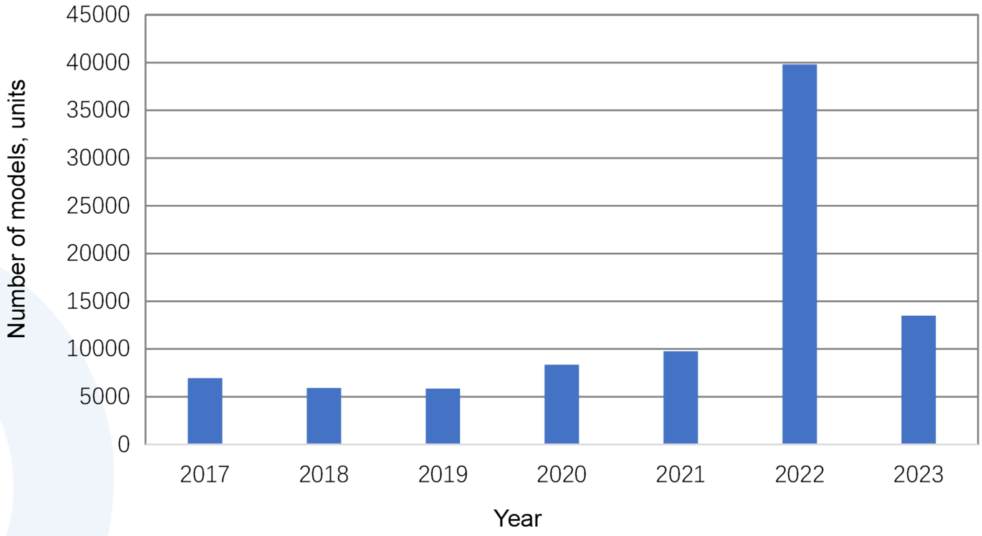

Figure 16 Number of machinery models with environmental protection information disclosed in China

Starting from June 2022, manufacturers and importers of electric machinery have been required to publicly disclose environmental protection information for electric machinery on the Motor Vehicle Environmental Protection Website. After the individual machine information is disclosed, a random machine list is generated, as shown in Figure 17.

非道路移动机械（电动机械）环保信息

信息公开编号：..................

XXXXXX 公司声明：本企业依据《中华人民共和国大气污染防治法》和生态环境部相关规定公开非道路移动机械环保信息，本企业对公开的所有内容的真实性、准确性、及时性和完整性负责。

第一部分 机械信息

1	机械型号：	
2	机械名称：	
3	商　　标：	
4	机械分类：	
5	机械的识别方法和位置：	
6	环保信息标签位置：	
7	机械环保代码位置：	
8	制造商名称：	
9	生产厂地址：	

第二部分 环保关键信息

10 驱动电机型号/生产企业：
11 驱动电机控制器型号/生产企业：
12 机械整机控制器型号/生产企业：
13 储能装置型号/生产企业：
14 储能装置总储电量（kWh）：

第三部分 制造商/进口企业信息

15 法人代表：
16 地　　址：
17 联系电话：

本信息内容及相关信息已上传至本公司官方网站（http://www.xxxxxx.com.cn）、生态环境部机动车和非道路移动机械环保信息公开平台（http://www.vecc.org.cn）。

信息公开时间：XXXX年XX月XX日

Figure 17 Disclosure of Environmental Information for Electric Machinery in China and the Machinery List

As of the end of 2023, 15 companies have disclosed information on 25 machinery models, as shown in Table 3, with the most models being loaders, totaling 11. Currently, the disclosure of environmental protection information for electric machinery is voluntary by companies, so some electric products, such as electric forklifts, have not been disclosed.

Table 3 Number of electric machinery models with environmental protection information disclosed in China.

Electrical Machinery Types	Number of Models
Loading machine	11
Seedling transplanter	1
Dump truck	4
Forklift truck	6
Excavator	1
Reach stacker	1
Crane	1

(2) Coding and registration

In 2019, the Ministry of Ecology and Environment issued the *Notice on Accelerating the Investigation and Coding Registration of Non-Road Mobile Machinery* (Environmental Office Air Letter [2019] No. 655), which began nationwide coding and registration for non-road mobile machinery, primarily construction machinery. By the end of 2022, a total of 3.223 million construction machinery units had been registered, and based on ownership estimates, the nationwide coding and registration rate for construction machinery is close to 40%.

(3) High-Emission Non-Road Mobile Machinery Prohibition Zones

After the implementation of the *Air Pollution Prevention and Control Law* in 2016, some cities gradually began to designate high-emission non-road mobile machinery prohibition zones. Following the release of the *Action Plan for Diesel Truck Pollution Control* at the end of 2018, the pace of designating high-emission non-road mobile machinery prohibition zones accelerated. The number of new prohibition zones designated each year is shown in Figure 18. By the end of 2023, a total of 315 cities at the prefecture level and above had designated high-emission non-road mobile machinery prohibition zones. Some cities that designated prohibition zones earlier have started revising these zones, expanding their scope or raising the emission requirements for machinery. Some cities have also designated general prohibition zones and key prohibition zones (such as Jinan). Currently, the main regulatory enforcement methods for high-emission non-road mobile machinery prohibition zones include smoke opacity testing and coding registration verification.

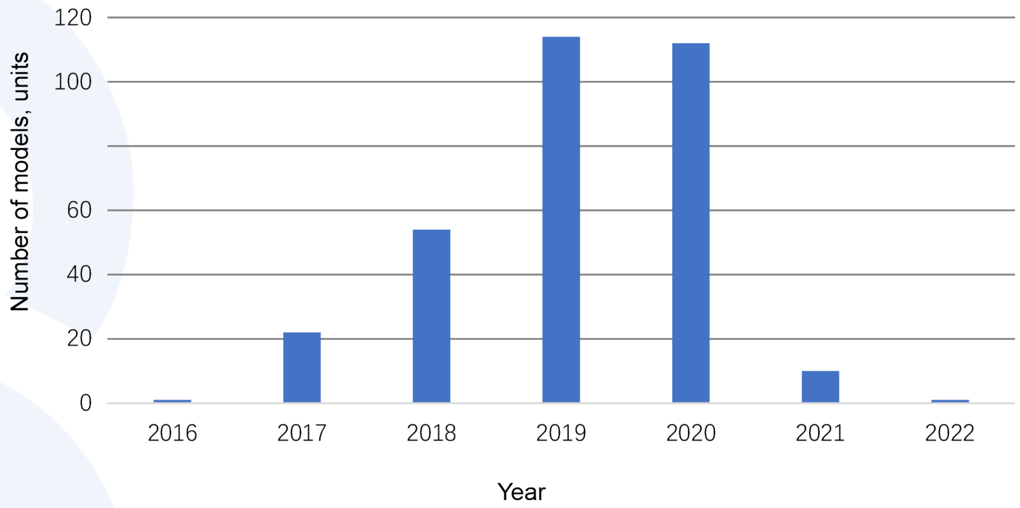

Figure 18 Number of high-emission non-road mobile machinery prohibition zones designated in China by year

(4) Elimination and Scrapping of Old Machinery

The *Air Pollution Prevention and Control Law*, the *Action Plan for Diesel Truck Pollution Control*, and other legal and policy documents have consistently encouraged and supported the scrapping of old non-road mobile machinery. In 2023, the State Council issued the *Air Quality Continuous Improvement Action Plan*, which proposed that by 2025, non-road mobile machinery that meets Stage I emission standards or below should be largely eliminated.

Since 2004, the country has implemented subsidy policies for old agricultural machinery, which has been the main method for eliminating and scrapping old agricultural machinery. However, the elimination of old construction machinery has been challenging due to the lack of mandatory scrapping systems and subsidy policies. Currently, the scrapping of old construction machinery has just begun in some provinces and cities.

<u>Shandong Province</u>

The *Shandong Province Work Plan for Pollution Emission Control of Non-Road Mobile Machinery* (Luhuanfa [2022] No. 1) proposes that by the end of 2024, non-road mobile machinery that meets Stage I or lower emission standards or is over 15 years old should be largely eliminated. The subsidy types include scrapping, trade-in, and engine replacement. Several cities in Shandong Province have issued implementation plans for the scrapping and updating of non-road mobile machinery, with public processes for scrapping subsidies.

Zhejiang Province

The *Zhejiang Province Work Plan for Promoting the Elimination and Replacement of Old Diesel Forklifts with New Energy Alternatives* (Zhehuanhan [2022] No. 325) proposes the elimination of Stage II and lower diesel forklifts and subsidies for the purchase of new energy forklifts. Various cities in Zhejiang Province have published their elimination plans and subsidy amounts, with Hangzhou's details shown in Table 4. In 2023, the Zhejiang Provincial Department of Ecology and Environment issued the *Notice on the Implementation of the Action Plan to Mitigate Polluted Weather Conditions in Zhejiang Province* (Zhehuanfa [2023] No. 18), which proposed a target for eliminating old machinery. By the end of 2025, 50,000 old non-road mobile machinery units should be eliminated, Stage II and lower diesel forklifts should be largely phased out, and engines meeting Stage IV or higher emission standards can be replaced where possible.

Table 4 Subsidy Standards for the Elimination and Replacement of Stage II and Below Diesel Forklifts in Hangzhou

New energy forklift rated lifting weight, tons	Subsidy standard for phasing out and updating (Yuan / unit)
M＜2.5	11,000
2.5≤M≤5	24,000
M＞5	40,000
Actual subsidy amount = out update allowances * elimination time coefficient, eliminate time coefficient: Scrap before July 31, 2023, eliminate time coefficient is 1.0; Scrap before December 31, 2023, eliminate time coefficient is 0.7; Scrap before June 30, 2024, out of time coefficient is 0.5; Scrap before July 1, 2024 (including), eliminate time coefficient is 0.	

Note: The elimination time coefficient is subject to the recycling certificate of scrapped diesel forklift in Hangzhou.

(5) Other Regulatory Measures

Currently, other measures used for the regulation of non-road mobile machinery include machinery entry and exit registration, electronic fencing, and emissions testing for machinery entering low-emission zones.

1) <u>*Entry and Exit Registration*</u>

Platforms in provinces and cities such as Shandong, Shijiazhuang, and Chengdu have entry and exit registration functions, allowing for the registration of machinery entering and exiting construction sites and logistics parks. Machinery that has not been coded or marked, does not meet the requirements for restricted areas, emits black smoke, or exceeds emission standards cannot enter the site for operations through the entry and exit registration system. Through this system, environmental departments can monitor the type, location, and machinery used at construction sites in real time, improving enforcement efficiency.

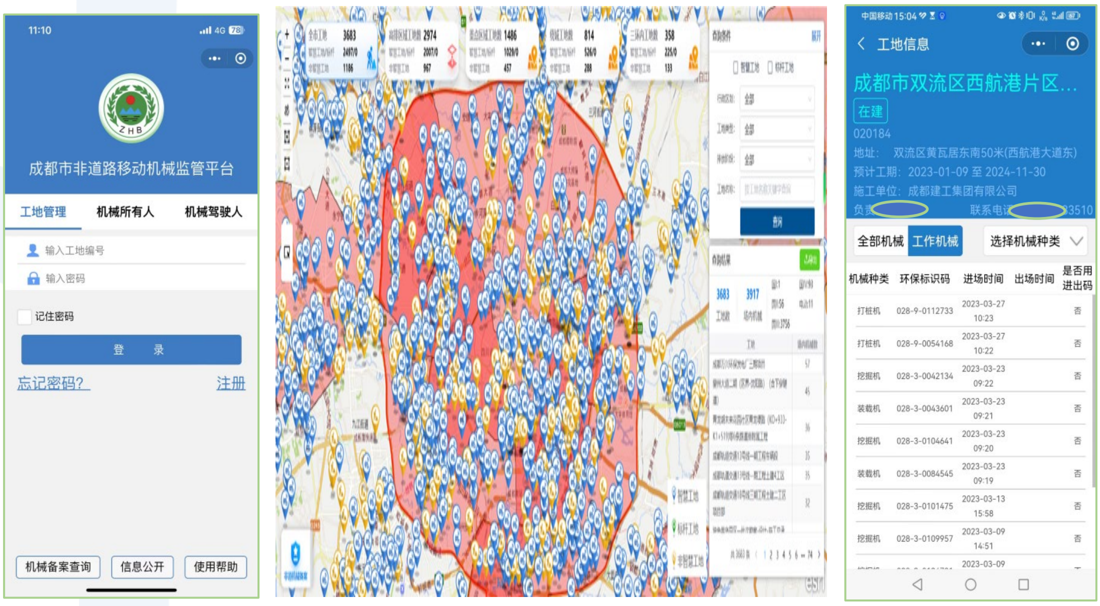

Figure 19 Chengdu Non-Road Mobile Machinery Regulatory Platform Entry and Exit Registration

Figure 20 Shandong Province Non-Road Mobile Machinery Regulatory Platform

2) *Electronic Fencing*

In 2022, Shandong Province issued the *Shandong Province Non-Road Mobile Machinery Online Monitoring and Networking Technical Requirements*. According to the requirements, non-road mobile machinery in use within the administrative boundaries of Shandong Province that meets the conditions for the installation of onboard terminals must install these terminals. By using remote monitoring and control, the machinery's location can be tracked in real-time. If any violations of low-emission zone management regulations occur, an "electronic fence" can be set up to trigger an alarm. By the end of 2023, 220,000 non-road mobile machinery units in Shandong Province had been equipped with real-time location monitoring devices. In addition to Shandong, some cities in Henan and Shanxi provinces also adopted electronic fencing.

8. What are the recommendations for the development of zero-emission in the non-road mobile machinery sector?

(1) Improve Laws and Regulations

The current issues with the laws and regulations mainly include:

According to the *Air Pollution Prevention and Control Law*, the supervision of newly produced machinery mainly relies on information disclosure and compliance monitoring. However, there is currently a lack of legal basis for penalties related to information disclosure. There are no requirements for the scrapping of old machinery, and an environmental recall system has not yet been established. Additionally, there are no scrapping regulations, and newer regulatory measures (such as coding and registration, online monitoring, opacity emission testing for in-use machinery, fuel quality regulation, etc.) still lack support from higher-level laws.

In some provinces and cities, local air pollution regulations and mobile source-specific regulations do not provide clear and detailed stipulations in line with the *Air Pollution Prevention and Control Law* and other related requirements. While the *Air Pollution Prevention and Control Law* mandates penalties for violations of high-emission non-road mobile machinery prohibition zones, some local regulations do not have corresponding penalties. Coding and registration are also only mandated in the local regulations of certain provinces and cities.

Based on the current state of laws and regulations, the following recommendations are proposed:

1) Improve Environmental Information Disclosure Requirements

Clearly state that environmental information should be disclosed for the engine models, machinery models, and individual machine information for newly produced, sold, and imported non-road mobile machinery.

Clearly define the law enforcement subjects, targets, and penalties for different types of violations.

2) Improve Supervision Requirements During the In-Use Stage

Improve the regulations for high-emission non-road mobile machinery prohibition zones, clarifying the requirements for machinery entering these zones, as well as the violations, penalties, and penalty amounts for non-compliance.

Add coding and registration requirements, specifying the responsibilities of the Ministry of Ecology and Environment, provincial and municipal environmental departments, and other relevant agencies.

Strengthen the responsibility of owners/users: owners, drivers, or operators of non-road mobile machinery should ensure the proper functioning of pollution control devices, onboard emission diagnostic systems, remote emission management terminals, and other equipment, and should use qualified fuel and urea solutions.

Implement mandatory scrapping for non-road mobile machinery that continues to fail to meet national emission standards after multiple repairs.

3) Improve Regulatory Measures

i Establish a Comprehensive Law Enforcement and Supervision Platform for Non-Road Mobile Machinery

The main management requirements for non-road mobile machinery include environmental information disclosure and compliance with emission standards for newly produced (including imported) machinery, coding and registration, opacity compliance, and fuel quality requirements for in-use machinery. Non-road diesel machinery in the National IV stage is required to install OBD systems, online emission monitoring systems, and location systems. These measures provide foundational tools for managing low-emission control zones for non-road mobile machinery. Additionally, for low-emission zones, various regulatory requirements have been introduced, such as entry and exit registration, electronic fencing, construction site registration, and the installation of real-time location systems on in-use machinery.

To improve regulatory efficiency and strengthen oversight of the entire lifecycle of non-road mobile machinery, it is recommended to establish a comprehensive law enforcement and supervision platform for non-road mobile machinery based on the above regulatory measures and requirements. This platform should gradually establish and improve systems for registration, transfer, modification, inspection, and other management processes for non-road mobile machinery, forming a "one machine, one file" environmental management model. This approach will gradually address challenges such as unclear data and difficulties in cross-regional enforcement and supervision.

ii Establish a Multi-Department Joint supervision mechanism

The *Air Pollution Prevention and Control Law* states that ecological and environmental departments, in collaboration with relevant departments such as transportation, housing and urban-rural construction, agriculture, and water administration, should supervise and inspect the air pollutant emissions of non-road mobile machinery. Machinery that does not meet emission standards should not be used. To enhance coordination among departments, it is recommended that the ecological and environmental department collaborate with the housing and urban-rural construction and transportation departments for joint supervision of construction machinery at construction sites and ports; and with the agriculture department for joint supervision that combines agricultural machinery information disclosure with agricultural machinery subsidies.

- To strengthen the involvement of relevant departments in the supervision of non-road mobile machinery, the following approaches are recommended:
- During the bidding/contract process, industry authorities should urge construction units to include non-road mobile machinery emission requirements in the bidding documents and contract clauses.

- During construction/use, establish a machinery entry and exit registration system, educate and guide the users of non-road mobile machinery to purchase qualified fuels and perform timely maintenance and repairs.
- Establish a joint working mechanism, where relevant departments cooperate with the ecological and environmental departments to conduct joint supervision and law enforcement inspections, including exhaust emission compliance, machinery coding and registration, and fuel quality inspections, with shared regulatory data.

iii Improve regulatory Measures

- Improve the Definition and Enforcement of Low-Emission Zones: It is recommended to develop technical specifications for defining low-emission zones and strengthen the combination of "human" and "technological" defenses in law enforcement. This would make full use of on-site personnel for random checks (such as verifying environmental information disclosure, opacity testing, and coding registration) and online technologies (such as online monitoring, entry and exit registration, and electronic fencing) to enhance the effectiveness of supervision in low-emission zones. Expanding the scope of low-emission zones and encouraging county-level cities and counties to designate low-emission zones within their administrative regions is also suggested.
- Improve the Coding and Registration System: It is recommended to research and release the *Non-Road Mobile Machinery Coding and Registration Technical Specifications* to standardize the coding and registration work across regions. The registration process should be optimized, ideally completing the coding and registration at the machinery sales stage, implementing a "one machine, one code" system upon sale. Additionally, improving data sharing for coding and registration is essential, ensuring that each machine has a unique code and that registration data is universally applicable nationwide.
- Gradually Establish an Environmental Recall Management System: The *Motor Vehicle Emission Recall Management Regulations* suggest that non-road mobile machinery follow similar guidelines for environmental recalls. However, no recalls have occurred for non-road mobile machinery to date. Given the differences in usage scenarios and regulatory methods (such as the absence of annual inspection systems) between non-road mobile machinery and motor vehicles, it is recommended to conduct specific research on environmental recalls for non-road mobile machinery and gradually establish a recall system.

- Establish a Mechanism for the Elimination and Scrapping of Old Machinery: It is recommended to encourage and guide the elimination of old machinery through strengthened emissions regulation and reduced operational space for outdated equipment. Research should be conducted to establish disposal norms for non-road mobile machinery, drawing from the principles of "voluntary for farmers, supported by the state, convenient and efficient, and promoting renewal" used in agricultural machinery scrapping. A mandatory and voluntary combined system for the scraping of old non-road mobile machinery should be developed.

(2) Accelerate the promotion and Application of new energy machinery

Currently, there are several issues with the promotion and application of new energy machinery: Policy is Too Macro: The electrification goals and specific implementation measures are unclear, and there is insufficient guidance for manufacturing companies. Existing policies and regulations for electric construction machinery are primarily encouraging and guiding, with few executable measures. Additionally, the policy goals are not clearly defined. Only forklifts are mentioned in the *Action Plan for Electrification of Public Sector Vehicles* with an electrification ratio target of over 55% during the 14th Five-Year Plan, while no electrification targets exist for other machinery. High Purchase Costs of Electric Machinery: There is insufficient incentive for end-users to purchase electric machinery. While electric construction machinery offers clear cost advantages over fuel-powered machinery of the same power, the high initial purchase cost (e.g., a pure electric loader costs about 800,000 RMB, approximately 2.3 times the price of a fuel-powered loader) and long cost recovery periods make it less attractive to end-users. The marketization process is slow due to the lack of environmental and economic policy incentives.

To accelerate the promotion and application of electric construction machinery, it is recommended:

- Research and Set Electrification Targets for Construction Machinery: Strengthen research and analysis of electric construction machinery production and usage, and, in line with the national "dual carbon" goals and other macro demands, establish electrification targets for various types of construction machinery in stages to guide industry development.
- Promote the Application of Electric Construction Machinery in Key Industries: Use a combination of policies to integrate the promotion of electric construction machinery with key industry performance grading, ultra-low emission transformation, and near-zero carbon emission demonstration projects. Priority should be given to promoting the use of

electric machinery in ports, airports, railway cargo yards, mines, and industries such as steel, thermal power, and coking.

- Implement Zero-Emission Control Zones and Zero-Emission Construction Sites: Research and define zero-emission control zones and implement zero-emission construction sites. Explore the use of shared and leased machinery to promote the application of electric construction machinery. It is recommended to prioritize the promotion of electric machinery in government procurement and construction projects and gradually expand this to all construction sites.
- Improve Incentive Measures: Support the promotion and application of electric construction machinery through policies such as tax reductions or exemptions for manufacturers, subsidies or preferential loans for purchases, operational electricity subsidies, support for charging infrastructure planning and construction, and government funding for "retrofit and investment" programs.
- Play a Leading Role in Standards: In the next phase of emission standards for diesel non-road mobile machinery, research and include greenhouse gas co-control requirements to promote the development of cleaner machinery.

II Shipping and Port Section

This section provides a comprehensive overview of the emission reduction policies and practices in the shipping and port sectors at the international, regional, and national levels. By analyzing emission reduction pathways and technology applications both domestically and internationally, this section summarizes the current status, challenges, and opportunities in pollution reduction and carbon reduction for the shipping industry and ports. It offers policy recommendations to further promote the development of green shipping and ports. These measures include improving laws and regulations, enhancing international cooperation, promoting clean energy technologies, and optimizing shipping and port management models to achieve the sustainable development goals of the

Keywords: Greenhouse gas reduction, coastal and inland vessels, green and intelligent development, shore power facilities, port pollution reduction and carbon reduction

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Chapter II Shipping and Port Section

9. What is the global strategic framework for greenhouse gas reduction in the shipping industry[38]?

The global shipping industry accounts for about 80% of global transport volume, but its emissions represent only 10% of the transport sector's emissions and 3% of global greenhouse gas emissions. In recent years, the growth rate of emissions from shipping has outpaced most other industries. Some researchers have stated that, without action, the shipping industry could account for 10-13% of global emissions within a few decades.

In April 2018, the International Maritime Organization (IMO) adopted the initial greenhouse gas reduction strategy for ships. This policy framework set key targets, including reducing the annual greenhouse gas emissions from international shipping by at least half by 2050 compared to 2008 levels. Additionally, it set a goal to gradually achieve zero emissions from ships by the 21st century. The carbon intensity of international shipping should be reduced by at least 40% by 2030, with the aim of reducing carbon intensity by 70% by 2050, compared to 2008 levels.

In July 2023, IMO revised its initial greenhouse gas reduction strategy, with member countries agreeing on the following goals: (1) achieving net zero greenhouse gas emissions by around 2050; (2) setting "emission reduction milestones" with a 20% reduction in total emissions by 2030 compared to 2008 levels, with an aspirational goal of 30%; a 70% reduction by 2040, with a goal of 80%; (3) applying zero or near-zero greenhouse gas emission technologies, fuels, and/or energy, with at least 5% of international shipping's energy use by 2030 derived from such sources, aiming for 10%.

Compared to the IMO's 2018 strategy, the revised version has significantly tightened the emission reduction targets. The previous strategy aimed for a 50% reduction by 2050, without setting interim targets. The revision introduces two major improvements: the establishment of a net-zero emission date (before or around 2050) and a focus on lifecycle emissions. For measuring lifecycle greenhouse gas emissions, the revised strategy uses CO_2e100 as an indicator, which is based on the 100-year global warming potential of CO_2, methane, and nitrous oxide, converting them to carbon dioxide equivalent emissions.

[38] Comer B, Carvalho F. IMO's newly revised GHG strategy: what it means for shipping and the Paris Agreement. The International Council on Clean Transportation, 2023.

Although the reduction strategy itself is not legally binding, the accompanying management measures can have legal force. Following the introduction of the initial greenhouse gas reduction strategy, IMO introduced several "short-term measures" for controlling greenhouse gas emissions from ships. Two of these measures took effect in 2023: the existing Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII). These measures are now incorporated into the International Convention for the Prevention of Pollution from Ships (MARPOL) and are legally binding. However, these measures are currently insufficient to achieve significant emissions reductions. The EEXI index is not stringent enough; according to the International Council on Clean Transportation's assessment, it is expected to reduce only 1% [39] of future emissions by 2030. The CII index merely ranks ships from A to E. Both measures are expected to be revised by January 1, 2026. To improve these measures more effectively, it is recommended to include carbon dioxide equivalent emissions in the regulations, rather than just monitoring CO_2, and to extend the scope of the CII to cover lifecycle emissions (WTW) while tightening the emission reduction requirements.

In addition to the short-term measures, IMO is also discussing mid-term measures, which are expected to be implemented as early as 2027. These measures will include both technical and economic measures, referred to by IMO as a "package." The technical measures are expected to include the Greenhouse Gas Fuel Standard (GFS), which will progressively reduce the carbon dioxide (WTW CO_2e) intensity limits of ship fuels. Economic measures are less clear, but key considerations include greenhouse gas fuel taxes, tax incentives, and trade regulation schemes. Regarding the Greenhouse Gas Fuel Standard (GFS), model simulations show that to meet the 1.5°C temperature control target, shipping fuel greenhouse gas intensity must be reduced by 38% by 2030, 97% by 2040, and 100% by 2050.

10. What is the progress of international green shipping corridors?

In November 2021, during the 26th Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) in Glasgow, 22 countries including the UK, the US, France, Germany, Japan, and Australia signed the *Clydebank Declaration on Green Shipping Corridors*. The declaration outlined the goal of establishing more than six green shipping corridors, or "zero-emission shipping lanes," between two or more ports globally

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[39] Rutherford D, Mao X, Comer B. Potential CO_2 reduction under the energy efficiency existing ship index. The International Council on Clean Transportation, 2020.

by 2025, with plans to expand the number of green shipping corridors before 2030. This initiative aims to help the global shipping industry achieve full decarbonization by 2050. This marked the formal introduction of the concept of "green shipping corridors" at the international level.

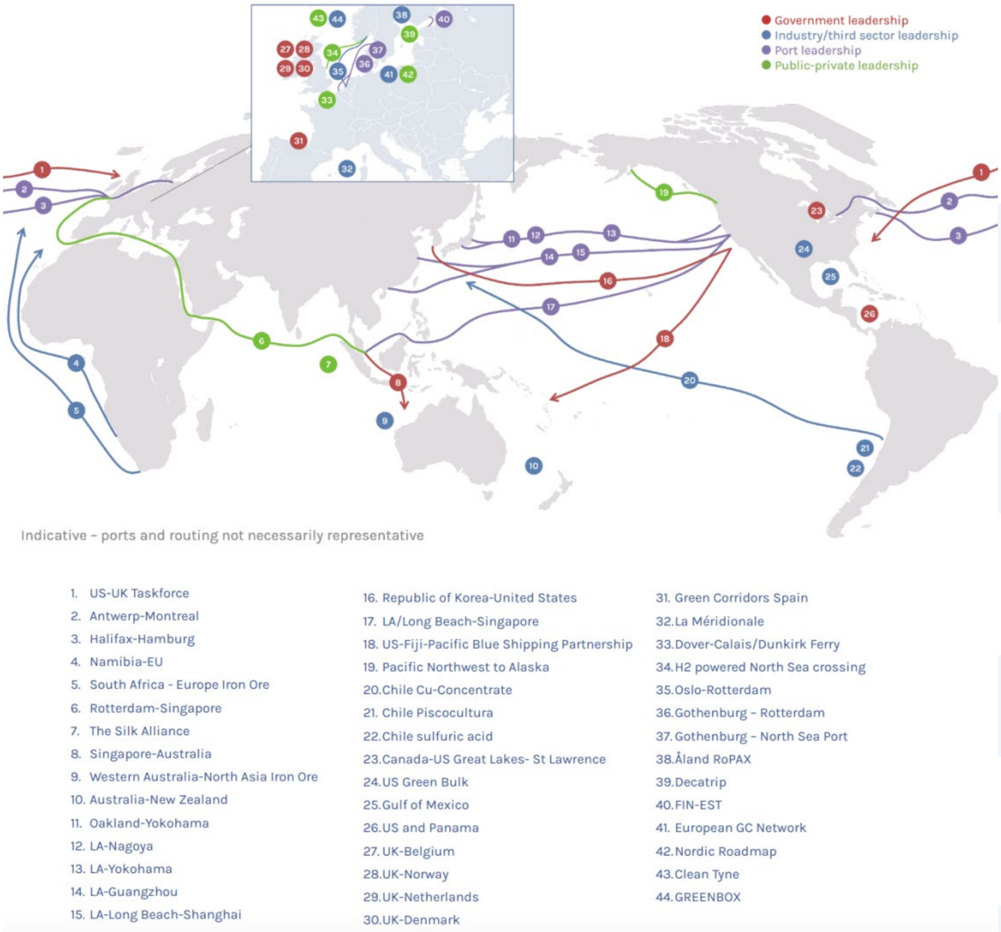
In terms of development stages, globally, half of the green shipping corridor initiatives are still in the early stages of establishing partnerships and assessing feasibility. The rest are in the stage of evaluating the feasibility of specific shipping routes or formulating implementation plans and goals. No green shipping corridors have yet entered the operational phase. However, compared to 2022, by 2023, 12 green shipping corridors have released their implementation plans or goals, indicating that green shipping corridors are gradually moving toward a clearer and more mature stage.

Source: Global Maritime Forum, Annual Progress Report on Green Shipping Corridors

Figure 21 Distribution of Green Shipping Corridor Development Stages (As of the End of 2023)

According to a report released by the Global Maritime Forum[40], by the end of 2023, there were a total of 44 green shipping corridor initiatives globally (as shown in Figure 22), an increase of 23 compared to the statistics at the end of 2022. In terms of alternative fuel types, the main fuels used include methanol (14 corridors), ammonia fuel (9 corridors), hydrogen fuel (6 corridors), electrification (4 corridors), and biomass fuel (2 corridors), with the remaining corridors yet to determine their alternative fuel solutions or plans. Compared to 2022, the number of green shipping corridors involving methanol increased by 11, ammonia fuel by 6, hydrogen fuel by 2, and electrification by 2. Overall, methanol and ammonia fuels are more favored. In terms of vessel types, container shipping corridors are the most common, with 11 existing.

[40] Data Source: Annual Progress Report on Green Shipping Corridors published by the Global Maritime Forum.



Source: Global Maritime Forum, Annual Progress Report on Green Shipping Corridors

Figure 22 Global Green Shipping Corridor Initiatives (As of the End of 2023)

The world's first and China's only international green shipping corridor is the "Shanghai-Los Angeles Green Shipping Corridor." The initiative was jointly launched by Shanghai Port and Los Angeles Port in January 2022. After a year of efforts, the parties reached an agreement on the implementation plan outline, and in October 2023, the *Shanghai-Los Angeles Green Shipping Corridor Implementation Plan Outline* was officially released. The plan outlines a "two-step" approach, providing a clear path and timeline for the implementation of this green shipping corridor. According to the implementation plan, starting in 2025, shipping company partners will deploy vessels with full lifecycle low-carbon or zero-carbon emissions capabilities in this corridor. By 2030, the feasibility of the world's first full lifecycle zero-carbon emissions container ship (or fleet) will be demonstrated along this corridor. Port partners will take measures to reduce carbon emissions from terminal operations. Cargo owner partners will set goals and agree with carriers to use full lifecycle zero-carbon shipping services. During this process, stakeholders will track and report carbon emissions and assess decarbonization progress, aiming to make this trans-Pacific green corridor a model for global cooperation in the green, low-carbon, and sustainable development of the shipping industry.

11. What are the shipping emission reduction actions and policies in major countries and regions?

In response to the international trend of shipping emission reduction, major maritime nations have also developed medium- and long-term carbon reduction development plans for their domestic shipping industries, such as the *Norwegian Green Shipping Action Plan* (2019), the *Japan Shipping Zero-Emission Roadmap* (2020), and *Maritime 2050* by the UK (2019). These plans include financial support and tax incentives, actively guiding market participants in the shipping industry, universities, and research institutions to engage in technological research, development, and production of green ships[41].

(1) Europe - Norway, Netherlands, United Kingdom

Norway: Norway is a global leader in the green transition in shipping. The government has set a target to reduce carbon emissions from domestic shipping and fishing vessels by 50% by 2030. The government will incorporate zero-emission and low-emission principles in the procurement process for ferries and high-speed boats and has established long-term subsidies and tax incentives for the purchase of environmentally friendly vessels. Norway is engaging in dialogue with industry partners to discuss the possibility of a green fleet renewal memorandum of understanding for freight ships. The government also encourages companies to support the development of related technologies and infrastructure, such as Enova, a state-owned company under the Norwegian Royal Petroleum Ministry, which has allocated 1.5 billion NOK since 2015 for green ship projects, including the installation of batteries and charging infrastructure for various types of vessels.

Netherlands: The Netherlands has a fleet of about 6,500 inland vessels, ranging in size from 350 to 6,000 tons, which transport containers, bulk goods, chemicals, and fuel across all canals and rivers in Europe. The Dutch inland shipping sector transports more than one million tons of cargo daily, accounting for 31% of the country's total freight transport. According to national reports, the total emissions from the Dutch inland shipping fleet are 1.6 million tons of CO_2 and 21,200 tons of nitrogen oxides. Compared to the total freight transport

[41] ZHENG Jie, LIU Cungen, LIN Zhongqin. Low-Carbon Development of Green Ships and Related Strategies [J]. *Strategic Study of CAE*, 2020, 22(6):9.

(including road and rail), inland shipping accounts for 13% of CO_2 emissions and 37% of nitrogen oxides. Inland shipping represents less than 5% of total CO_2 emissions in the transport sector (including air freight). Under the *Green Agreement for Shipping and Inland Shipping and Ports*, the Netherlands aims to reduce atmospheric emissions from inland shipping: by 2030, reduce CO_2 emissions from the inland fleet by 40-50% compared to 2015 levels; by 2035, reduce pollution emissions from inland shipping by 35-50% compared to 2015 levels[42].

United Kingdom: The UK believes that zero-emission vessels need to be in service by 2030. Any vessel project funded, designed, or built by 2020 must consider transitioning to non-fossil fuel propulsion in the later stages of the vessel's life. To achieve the decarbonization plan for ships by 2030, the UK has set the following development pathways: clearly define the demand for zero-emission ships in the *Low Carbon Action 2050* plan, conduct feasibility assessments for zero-emission ships, identify the gaps between existing ships and zero-emission ships, compare different decarbonization solutions, identify the driving factors for transitioning to zero-emission ships, and formulate low-carbon action plans to promote the full development of zero-emission ships. Lloyd's Register is assessing the impact factors and feasibility of zero-emission ship technologies, with the key components of the technologies listed in Table 5.

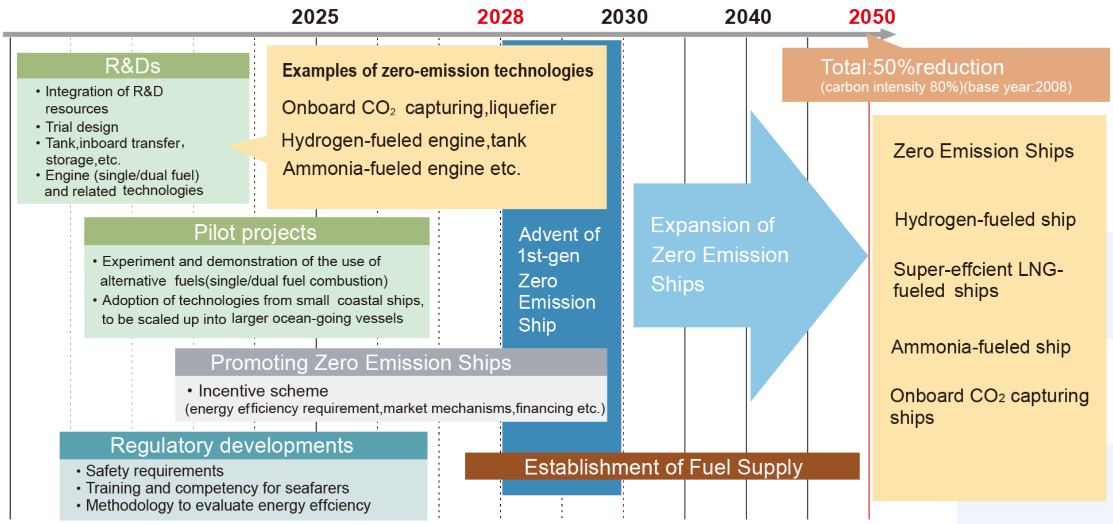
[42] Data Source: *Inland shipping emissions increasingly monitored* published by the Netherlands Private Rhine Central Shipping Cooperative.

Table 5 Key Technologies and Main Components of Zero-Emission Ships in the United Kingdom

No.	New Energy Technology	Main Components
1	Electric power	Battery/ Electric motor
2	Hydrogen mixture	Hydrogen storage/ Battery/ Fuel cell/ Electric motor
3	Hydrogen fuel cell	Hydrogen storage/ Fuel cell/ Electric motor
4	Hydrogen internal combustion engine	Hydrogen storage/ Reserve oil tank/ Dual-fuel internal combustion engine
5	Ammonia fuel cell	Ammonia storage/ Reformer/ Fuel cell/ Electric motor
6	Ammonia internal combustion engine	Ammonia storage/ Reserve oil tank/ Dual-fuel internal combustion engine
7	Biofuel	Biogenic fuel tank/ Internal combustion engine

(2) Asia – Japan, South Korea, Singapore

Japan: Japan is committed to introducing ultra-low emission or zero-emission ships by 2030, with a goal to achieve a 90% or more reduction in greenhouse gas emissions compared to 2008 levels. Japan views the development of clean alternative fuels as an effective way to promote the growth of green ships. The country believes that there are two main possibilities for achieving alternative fuels for shipping vessels: Using Liquefied Natural Gas (LNG) as a transitional alternative fuel to address shipping carbon emissions, leveraging existing LNG infrastructure while gradually increasing the use of bio-methane (CH_4) and carbon-cycled CH_4.Simultaneously increasing the use of hydrogen and ammonia fuels alongside LNG, as the combustion of liquefied hydrogen and ammonia without ignition does not emit CO_2 and can play an important role in reducing total greenhouse gas emissions from international shipping. The zero-carbon development roadmap that Japan has formulated is as follows:



Source: Roadmap to Zero Emission from International Shipping, Japan Ship Technology Research Association

Figure 23 Japan's Zero-Carbon Ship Roadmap

South Korea: In December 2020, the South Korean government announced its 2050 net-zero vision. To support this vision, the Ministry of Finance developed the *2050 Net-Zero Roadmap for the Marine and Fisheries Sector*. In February 2023, the Ministry also formulated the *International Shipping Decarbonization Strategy*, which includes policies and technologies for reducing greenhouse gases. In the *International Shipping Decarbonization Strategy*, South Korea not only set the goal of achieving net-zero emissions in international shipping by 2050, but also established two intermediate milestones: a 60% reduction in emissions by 2030 compared to 2018, and an 80% reduction by 2040. South Korea plans to achieve the international shipping net-zero goal through four major strategies and twelve actions. According to the *2030 Green Shipping-K (Korean Green Shipping) Promotion Strategy (2021-2030)*, the Ministry of Finance announced plans to retrofit a total of 388 government vessels into green ships by 2030. Among them, 199 vessels over 25 years old will be replaced with green ships, while 189 vessels under 10 years old will be retrofitted with Diesel Particulate Filters (DPF). In addition to replacing ships, the South Korean government launched a Green Ship Certification Program in 2021, aimed at ensuring the quality of emerging zero-carbon shipping technologies and supporting their promotion and application. The certification will be assessed based on the effectiveness of green ships and green ship equipment in reducing greenhouse gases and air pollutants, as well as the complexity of the technology, with five levels of certification.

Table 6 Four Major Strategies and Twelve Actions for Decarbonizing Shipping in South Korea

Four Strategies	Twelve Actions
Steering towards eco-friendly ships and related regulations	Retrofitting eco-friendly ship structures
	Support for ship retrofitting and facility improvement
	Operational ship carbon emission reduction and carbon management
Improving the investment environment for the shipping industry	Providing financial and tax support for eco-friendly ship operators
	Developing plans to support the eco-friendly transition of small and medium shipping enterprises
	Creating eco-friendly transition models to support cooperation between shipowners and cargo owners
Expanding eco-friendly technologies and fuel filling facility	Eco-friendly ship technology development and commercialization
	Commercialization of future fuels and the construction of fuel supply chain infrastructure
	Deregulation to facilitate private enterprise entry
Establishing zero-carbon shipping routes and strengthening international cooperation	Promoting global green shipping programs
	Establishing an international environmental governance system led by South Korea
	Establishing an international shipping decarbonization council comprising industry, academia, research, and government

Singapore: In 2022, the Maritime and Port Authority of Singapore (MPA) released the *Singapore Maritime Decarbonization Blueprint: Towards 2050*[43], aimed at achieving its climate goals while strengthening Singapore's position as a global leading hub port and international maritime center. The blueprint

[43] Maritime and Port Authority of Singapore (2024), Maritime Singapore Decarbonisation Blueprint: Working Towards 2050. https://www.mpa.gov.sg/maritime-singapore/sustainability/maritime-singapore-decarbonisation-blueprint

sets low and zero-carbon targets for ports and port-related vessels: By 2030, the carbon emissions from port terminals will be reduced by at least 60% compared to 2005 levels; by 2050, port terminals will achieve net-zero emissions; by 2030, the carbon emissions from port-related vessels will be reduced by 15% compared to 2021 levels through low-carbon energy solutions; and by 2050, carbon emissions from port-related vessels will be reduced by 50% compared to 2030 levels through the shift to fully electric propulsion and net-zero fuels. Although the blueprint does not set any targets for low and zero-carbon fuels, Singapore has not stopped its progress. On July 27, 2023, Singapore completed the world's first methanol bunkering operation for container ships. In December of the same year, the MPA invited interested parties to submit proposals for supplying methanol as a marine fuel in Singapore port, with the aim of gathering suggestions for implementing an end-to-end methanol bunkering solution in Singapore starting in 2025 [44]. Additionally, to explore the decarbonization potential of biofuels in shipping, Singapore has established a framework for fuel suppliers to supply biofuels to vessels within Singapore port[45].

(3) United States of America

The United States rejoined the *Paris Agreement*, which took effect on February 19, 2021. In April 2021, the U.S. government officially submitted its new Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), with the goal of reducing greenhouse gas emissions by 50-52% from 2005 levels by 2030. The U.S. revised NDC identifies transportation as one of the six major sectors, with shipping being listed as one of the transportation modes still heavily dependent on fossil fuels.

In January 2023, the U.S. Department of Energy, Department of Transportation, Environmental Protection Agency, and the Department of Housing and Urban Development jointly released the *U.S. Transportation Decarbonization Blueprint*[46], aiming to establish a clean, safe, reliable, convenient, low-cost, and

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[44] Maritime and Port Authority of Singapore (2023), Expression of Interest for the Supply of Methanol as a Marine Bunker Fuel in the Port of Singapore. https://www.mpa.gov.sg/media-centre/details/expression-of-interest-for-the-supply-of-methanol-as-a-marine-bunker-fuel-in-the-port-of-singapore#:~:text=The%20EOI%20aims%20to%20gather, vessels%20in%20the%20coming%20years.

[45] Maritime and Port Authority of Singapore (2024), Supply of Biofuel within the Port of Singapore to Vessels. https://www.mpa.gov.sg/port-marine-ops/marine-services/bunkering/biofuel-bunkering

[46] U.S. Department of Energy, Department of Transportation, Environmental Protection Agency and Department of Housing and Urban Development (2023), The U.S. National Blueprint for Transportation Decarbonization. https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf

equitable transportation system. The blueprint divides the U.S. transportation clean transformation into three phases:

Now to 2030: Drive the deployment of clean transportation tools and facilities through research and investment.

2030-2040: Accelerate the implementation of clean transportation solutions, ensuring the necessary infrastructure for clean transport is installed and fully integrated into the energy system.

2040-2050: Complete an equitable clean transition to achieve net-zero emissions.

Shipping will prioritize decarbonization efforts in the following areas:

1) **Research and Innovation on Viable Alternative Fuels and Emerging Technologies**: Identifying the most promising decarbonization pathways for shipping, including biofuels, ammonia, hydrogen, methanol, batteries, shore power, energy efficiency, hybrid propulsion, renewable energy, and carbon capture technologies.
2) **Strengthening International and Domestic Stakeholder Cooperation**: Developing and implementing effective decarbonization strategies and regulations. For example, the U.S. Department of Energy co-leads the *Zero Emission Shipping Innovation Mission*, which aims to transition at least 5% of the global deep-sea fleet to zero-emission fuels and ensure that by 2030, at least 10 ports across three continents will be capable of supplying zero-emission fuels.
3) **Funding Shipping Infrastructure Investments**: Supporting the design and planning of clean technology and fuel applications through existing and new national programs. For example, the *Inflation Reduction Act* provides funding for ports to develop climate action plans and purchase zero-carbon equipment.

Currently, the U.S. is pushing for the passage of the *Clean Shipping Act*[47]. If enacted, it would impose carbon intensity limits on fuels used by vessels over 400 gross tons:

2027-2029: A minimum 20% reduction in carbon intensity compared to baseline values.

2030-2034: A minimum 45% reduction in carbon intensity compared to

[47] US Committee on House - Energy and Commerce (2023), Clean Shipping Act. https://www.congress.gov/bill/118th-congress/house-bill/4024/text

baseline values.

2035-2039: A minimum 80% reduction in carbon intensity compared to baseline values.

2040 and beyond: Achieving a 100% reduction in carbon intensity compared to baseline values.

12. What policies has China implemented to promote emission reductions in the shipping industry?

China has undertaken many carbon reduction initiatives in the shipping industry under the "Dual Carbon" goals. In 2018, the Ministry of Transport issued the *Implementation Plan for Ship Air Pollution Control Zones* (Jiao Hai Fa [2018] 168), and the same year, it released the *Special Action Plan for Ship and Port Pollution Control (2015-2020)*. In 2019, the Ministry of Transport also issued several key documents, including the *Guiding Opinions on Building World-Class Ports*, *Opinions on Promoting the High-Quality Development of Yangtze River Shipping*, *Guiding Opinions on the Development of Smart Shipping*, and *Guiding Opinions on the Transformation and Upgrading of Ports*.

In 2022, the Ministry of Industry and Information Technology, the National Development and Reform Commission, the Ministry of Finance, the Ministry of Ecology and Environment, and the Ministry of Transport jointly released the *Implementation Opinions on Accelerating the Green and Smart Development of Inland Waterway Vessels*. This document set mid-term and short-term development goals: by 2025, breakthroughs in key green power technologies, such as LNG, batteries, methanol, and hydrogen fuels, will be achieved, and the smart technology level of vessels will significantly improve, with basic standards and specifications for inland vessel intelligence forming. By 2030, green and smart technologies for inland vessels will be fully deployed, supporting infrastructure, operation management, business models, and an industrial ecosystem will be more complete, with standardized and series-produced green smart vessels built in large quantities, and the industrial and supply chain levels significantly enhanced.

In the shipbuilding industry, five ministries, including the Ministry of Industry and Information Technology, released the *Green Development Action Plan for Shipbuilding Industry (2024-2030)* in December 2023. This plan aims to align with carbon peak and carbon neutrality goals, proposing that by 2025, alternative fuels and new energy technologies for ships will be synchronized with international standards, and the international market share of green vessels, such as those powered by LNG and methanol, will exceed 50%.

Regarding ship carbon emissions control standards, the Ministry of Transport has released several documents, including the *Standard Ship Model Indicator System for Inland Waterway Transport Vessels*, *Fuel Consumption Limits and Verification Methods for Operating Ships*, *CO_2 Emission Limits and Verification Methods for Operating Ships*, and the *Standardized Management Regulations for Inland Waterway Transport Vessels*.

After the release of related documents by national ministries, various provinces and cities have also developed action plans based on their own development conditions. In 2022, Fujian Province issued the *2022 Fujian Province Electric Ship Industry Development Pilot Demonstration Implementation Plan*, which specifies further promotion of the electric ship industry, offering subsidies of up to 40% of the battery power system price for the first batch of ships, and 60% for the first demonstration projects. In August 2022, the Shanghai municipal government issued the *Shanghai Carbon Peak Implementation Plan*, aiming to improve vessel energy efficiency, accelerate the development of electric inland vessels, and actively promote LNG, biomass fuel, as well as explore the application of hydrogen and ammonia in ocean-going vessels. By 2030, it aims to improve the design efficiency of key transport vessels by 20% compared to 2020 levels and ensure that the share of clean energy vessels, such as those powered by LNG, exceeds 5%.

In April 2023, Hubei Province issued *Measures to Support the Green Smart Ship Industry Development Pilot Demonstration*, aiming to accelerate the research, design, manufacturing, and application of LNG, battery, methanol, hydrogen fuel, hybrid power, and smart vessels. In 2024, Jiangsu Province released the *Three-Year Action Plan for Building a More Distinctive "Water Transport Jiangsu" (2024-2026)*. This plan aims to accelerate the development of green vessels, vigorously promote energy-saving and environmental protection technologies, and fully apply new energy and clean energy vessels while accelerating the elimination and updating of high-energy-consuming and high-emission vessels.

In March 2024, the State Council issued the *Action Plan for Large-Scale Equipment Upgrading and Consumption Replacement*, and in August, the Ministry of Transport and the National Development and Reform Commission issued the *Implementation Rules for the Scrapping and Updating Subsidy for Old Operating Ships*, clarifying policies to support the scrapping and updating of old operating ships and promoting the application of new energy vessels.

13. What is the current situation and trend of inland waterway shipping development in China?

Inland waterway shipping has long been responsible for the transportation of a large amount of goods and passengers and is an important part of China's integrated transportation system and the comprehensive utilization of water resources. It plays a vital role in promoting regional economic development, optimizing industrial layouts, and serving foreign trade[48].

China's inland waterways include the Yangtze River system, Huai River system, Yellow River system, Pearl River system, southwest rivers, Qiantang River system, and others. In recent years, significant achievements have been made in the construction of inland waterways, creating a waterway system centered around the Yangtze River mainline, Xijiang shipping mainline, Beijing-Hangzhou Grand Canal, and high-level waterway networks in the Yangtze River Delta and Pearl River Delta. The inland waterway system is well-connected, linking rivers to the sea[49]. By the end of 2023, the total navigable length of inland waterways in China was 128,200 kilometers, an increase of 184 kilometers compared to the previous year. The length of first-class, second-class, and third-class waterways accounted for 52.9% of the total inland waterway length, with 15.4 thousand kilometers of third-class and above waterways, accounting for 12% of the total length. The total length of various grades of inland waterways by the end of 2023 was as follows: 2,192 kilometers for Class I waterways, 4,471 kilometers for Class II waterways, 8,741 kilometers for Class III waterways, 11,717 kilometers for Class IV waterways, 7,375 kilometers for Class V waterways, 16,342 kilometers for Class VI waterways, and 16,989 kilometers for Class VII waterways. The length of other waterways was 60,300 kilometers[50].

By the end of 2023, China's inland ports had 16,433 operational berths, an increase of 551 berths. There were 469 berths for vessels of 10,000 tons and above, an increase of 18. Coastal ports had 5,590 production berths, an increase of 149, with 2,409 berths for vessels of 10,000 tons or more, an increase of 109. The total number of inland vessels by the end of 2023 was 106,600, with a deadweight of 154.33 million tons, a passenger capacity of 557,600, and a

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[48] Ministry of Transport of China (2020), Outline for the Development of Inland Waterway Transport (Transportation Planning and Development [2020] No. 54). http s://www.gov.cn/zhengce/zhengceku/2020-06/04/content_5517185.htm

[49] China Water Transport News (2023), Jointly Painting a New Picture of Inland Waterway Transport and Sounding the Charge for High-Quality Development. https://www.zgsyb.com/news.html?aid=669442

[50] Data Source: 2023 Report on the Operation of the Yangtze River Main Channel published by the Yangtze River Navigation Authority of the Ministry of Transport.

container capacity of 624,000 TEUs. The average tonnage of inland cargo ships on the Yangtze River mainline was 2,159 tons, and the average rated tonnage of ships passing through the Three Gorges locks was 5,672 tons[51].

In 2023, inland waterway freight volume reached 479.1 million tons, with a cargo turnover of 20,773 billion ton-kilometers. Passenger transport reached 258 million people, with a turnover of 53.77 billion person-kilometers. The total cargo throughput of inland ports was 613.9 million tons, an increase of 10.5%. The container throughput was 31 million TEUs, a growth of 4.9%. The volume of container rail-water intermodal transport reached 10.18 million TEUs, a growth of 15.9%. Inland port passenger throughput was 3.44 million people, a dramatic increase of 781.6%, while coastal port passenger throughput reached 75 million people, a growth of 94.9%.

China's development goal for inland waterway shipping is to establish a modern inland waterway shipping system that is highly regarded by the public, well-supported, and ranks among the top in the world by 2035, with full completion by 2050. The development of inland waterway shipping will focus on high-quality growth, emphasizing ecological priority, green development, coordinated and integrated development, overall advancement, collaborative development, innovation-driven progress, and scientific development. The plan includes scientifically developing and protecting inland waterway shipping resources, addressing developmental gaps, enhancing coordination with other modes of transport, improving efficiency and benefits, leveraging comparative advantages, and promoting the optimization of transport structure to achieve the modernization of inland waterway shipping, better serving the construction of a strong transportation nation and the implementation of national strategic priorities[52].

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[51] Data source: 2023 Yangtze River Shipping Development Report, released by the Yangtze River Shipping Administration under the Ministry of Transport.

[52] Ministry of Transport of China (2020), Outline for the Development of Inland River Navigation (Transportation Planning and Development [2020] No. 54). https://www.gov.cn/zhengce/zhengceku/2020-06/04/content_5517185.htm

14. What is the current carbon emission situation of inland waterway shipping in China? What challenges exist in achieving the "dual carbon" goals?

Carbon emissions from the transportation sector in China continue to account for an increasing proportion of the country's total emissions. In 2019, carbon emissions from the transportation sector accounted for about 10% of China's total emissions, with emissions from waterborne transport accounting for 6.5%[53] of the transportation sector's emissions. Inland waterway shipping is highly developed in China, and inland transport accounts for about 50% of the total waterborne cargo traffic, with carbon emissions from inland waterway transport making up around 3% of the total emissions from the transportation sector.

The main source of carbon emissions in the transportation sector is energy consumption, with ships and port machinery being the primary energy-consuming equipment in waterway transport. The main energy types consumed are diesel, heavy oil, gasoline, and electricity. Currently, domestic shipping consumes more than 11 million tons of fuel annually, while ships engaged in international voyages operated by Chinese shipping companies consume more than 13 million tons of fuel each year. The annual CO_2 emissions from shipping companies' vessels are approximately 78 million tons, of which domestic inland vessels emit about 34 million tons, and international vessels emit about 44 million tons[54]. More than 80% of emissions from inland vessels are concentrated in the navigable segments of river waters, with the highest emission intensity found in the lower reaches of the Yangtze River, the Pearl River, and their estuaries[55].

Research by the Ministry of Transport's Water Transport Research Institute has forecasted inland cargo transport volume and cargo turnover under baseline, 2°C, and 1.5°C scenarios. The findings suggest that, with the implementation of the "dual carbon" strategy, inland waterway shipping in China will continue to grow rapidly. The study also forecasted trends in carbon emissions from inland vessels, recommending a combination of technology, operations, and innovation for carbon reduction, with short-term, medium-term, and long-term implementation phases.

[53] LI Xiaoyi, TAN Xiaoyu, WU Rui, et al. Paths for Carbon Peak and Carbon Neutrality in Transport Sector in China [J]. Strategic Study of CAE, 2021,23(6):15-21.
[54] PENG Chuansheng. Current Situation and Trend of Green Shipping Development in China [J]. *China Maritime Safety*, 2022(000-006).
[55] Research Institute for Water Transport Science, Ministry of Transport. 2022.

Research by Tsinghua University[56], based on ship cargo volume, cargo transport distance, and ship emission intensity, calculated shipping carbon emissions. It also set up three carbon reduction scenarios for inland shipping on the Yangtze River and analyzed the key performance outcomes for each scenario. The research classified carbon reduction measures for Yangtze River inland vessels into the application of new energy vessels, the elimination of old vessels, ship size expansion, shore power usage, and operational energy-saving transformations. Among these, the application of new energy vessels can be further divided into LNG vessels, electric vessels, and other new energy vessels. The study showed the annual variation and growth rates of various carbon reduction measures in different scenarios. The carbon reduction potential coefficients for LNG-powered vessels are 10, for electric vessels 100, for methanol and hydrogen-powered vessels 100, for the elimination or retrofitting of old vessels 20, for shore power usage 1.67, and for operational energy-saving 15.

Large domestic shipping enterprises have taken the lead in shipping carbon reduction actions. For example, a major domestic enterprise forecasted the development trends of its inland shipping business under different scenarios. The planned carbon reduction measures include optimizing ship operations, replacing ship main engines, replacing with LNG vessels, replacing with electric vessels, reducing hull resistance, and using shore-based power systems. Carbon reduction contributions from different measures were also set according to scenarios, with the highest potential for carbon reduction from electric vessels, at approximately 99.9%.

For China's inland waterway shipping and inland shipping enterprises, the phased implementation of carbon reduction measures for inland vessels is essential to achieving the "dual carbon" goals. However, the implementation pathway should be tailored to the specific characteristics of inland waterway shipping and vessels. This involves not only dividing the implementation into phases on the timeline but also establishing different application scenarios for different vessel types and applicable emission reduction technologies.

Carbon reduction technologies for vessels can generally be divided into low-carbon/zero-carbon alternative fuels, low-carbon/zero-carbon power devices, operational energy efficiency management measures, and on-board CO_2 capture technologies. The IMO's greenhouse gas emission reduction pathway for shipping, organized by CCS, is shown in the following figure:

[56] LIU Huan. Global inland waterway and coastal shipping management and emissions. Tsinghua University, 2023.

Source: China Classification Society, "Outlook on Low Carbon Development in Shipping

Figure 24 Overview of Shipping Greenhouse Gas Emission Reduction

The demand for inland river shipping in China remains strong, and the Yangtze River waterway has now reached the conditions necessary for the large-scale and standardized development of vessels. To meet the green and low-carbon development trends in inland shipping, China has upgraded its vessels by incorporating advanced maritime technologies and adapting them to the specific characteristics of inland shipping. By breaking through key green and low-carbon technologies, China has significantly improved the green development level of inland shipping and reduced carbon emissions in this sector.

Over the past decade, China has made solid progress in the application of new energy and clean energy vessels, going from initial exploration to pilot applications and finally to demonstration. This has laid a strong foundation for large-scale promotion in the future. Currently, China has explored the use of multiple energy types, including LNG, electricity, methanol, and hydrogen, and adopted various propulsion technologies, such as gas fuel engines, lithium batteries, fuel cells, and hybrid technologies. As of now, more than 570 LNG-powered vessels have been built or are under construction, and over 350 battery-powered vessels are in operation. Research and pilot projects on methanol, hydrogen, and other fuels have also been carried out in some regions. Additionally, there has been a strong push to develop shore power facilities in ports and install receiving power equipment on domestic vessels to encourage the use of shore power while ships are docked.

Despite these advances, achieving the "dual carbon" goal for inland shipping still faces several challenges:

(1) **The Large Fleet Size**, **and Diverse Vessel Types**, and High **Leads to Significant Emission Reduction Pressure:** By the end of 2022, there were approximately 109,500 inland vessels in China, 150% more than in Europe and 111%[57] more than in the United States. The fleet is dominated by dry bulk carriers, container ships, oil tankers, chemical carriers, and roll-on/roll-off ships, with many other types such as passenger vessels, engineering vessels, government vessels, ferries, tugboats, and specialized ships. Compared to the Rhine River fleet in Europe, where 85% of vessels are standardized motor cargo ships, China's fleet is more diverse. While there has been progress in standardizing ship types for major waterways, many vessels still face issues with non-standardization.

The diversity in vessel types and the large number of smaller vessels present a significant challenge in reducing carbon emissions in inland shipping. Both government regulators and shipping companies must invest substantial time and effort to explore feasible emission reduction pathways, making this the primary challenge for achieving the "dual carbon" goal in inland shipping.

(2) **Outdated Vessel Technology and Low Green Development Levels:** Many inland vessels in China are small, outdated, and have low levels of engine technology, fuel efficiency, and high emissions. The fuel consumption per 100-ton kilometer is over 20% higher than that of developed countries, and energy efficiency is significantly lower compared to global standards. Currently, new energy and clean energy vessels account for less than 1% to 5% of the fleet, and the infrastructure for supporting charging and fueling stations is lagging, which impacts market investment confidence and increases the difficulty of achieving the "dual carbon" goals for inland shipping.

(3) **High Costs of Emission Reduction Technologies and Difficulty in Widespread Application**.: As the most promising long-term zero-carbon/reduction technology, the investment cost of new energy and clean energy technologies constitutes a high proportion of inland vessel construction costs. In the competitive and low-margin inland shipping market, shipping companies often have poor operational performance and lack sufficient funds to invest in new energy and clean energy vessels, making it difficult to promote their widespread application.

[57] Data Source: Global inland waterway and coastal shipping management and emissions by Tsinghua University

15. What are the emission reduction pathways for inland shipping in China?

To find suitable emission reduction technology pathways for China's inland shipping and inland vessels, the following analysis is conducted on the carbon reduction effects, technological status, and applicable scenarios of major carbon reduction/zero-carbon technologies, without considering the preparation source of fuels and power sources.

(1) Liquefied Natural Gas (LNG) powered vessels

Carbon reduction effect

The carbon emission parameters for natural gas and diesel are as follows:

Table 7 Carbon Emission Reference Coefficients for Diesel and Natural Gas

Name of Energy	Average Lower Heating Value (kJ/kg)	Carbon Content Per Unit of Energy (Tons of Carbon/ TJ)	Carbon Oxidation Rate	Carbon Dioxide Emission Factor ($kg\text{-}CO_2/kg$)
Diesel	42,652	20.2	0.98	3.0959
Natural gas	45,133-54,503	15.3	0.99	2.5066 ~3.0271

The average low calorific value of natural gas in China is the lower value listed in the table. Taking the CO_2 emission factor for natural gas as 2.5066 kg- CO_2/kg, the theoretical CO_2 reduction amount for 1 kg of natural gas relative to the same mass of diesel is 0.5893 kg, which corresponds to a reduction ratio of 19.03%. For the same calorific value, the reduction is 0.6236 kg and 20.14%. Compared to traditional fossil fuels, LNG can achieve about a 20% reduction in carbon emissions, but methane leakage during its use further lowers the carbon reduction effect, as methane itself is a greenhouse gas with a greenhouse effect 21[58] times that of CO_2.

Technical Status

Technologically, LNG fuel tanks, gas supply systems, and engines have all matured. Currently, technical optimization and cost reduction research is focused on reducing methane leakage, optimizing dynamic performance,

[58] Data Source: The official website of the Intergovernmental Panel on Climate Change (IPCC) of the United Nations, https://www.ipcc.ch.

and applying high-manganese steel materials for LNG low temperatures[59]. According to statistics from the International Gas Fuel Shipping Association (SGMF), as of November 2023, 426 LNG-powered ships have been put into operation globally, with 536 under construction. Over 400 LNG-powered ships have been built in China's inland waters. Meanwhile, LNG refueling facilities are developing rapidly, with 114 ports worldwide offering LNG refueling services for ships. However, LNG prices remain unstable, and China needs to accelerate the development of LNG refueling infrastructure and establish a price linkage mechanism to maintain price stability.

Applicable Scenarios

Currently, various types of ships worldwide have experience using LNG as fuel, and all types except LNG carriers are applicable.

When a ship uses natural gas as fuel, it is typically stored on board in liquid form as LNG after being cryogenically liquefied. There are two main types of LNG fuel tanks, with the C-type fuel tank being suitable for China's inland small and medium-sized vessels. LNG has a lower density than diesel, so tanks storing the same mass and calorific value of LNG need to be much larger. Additionally, due to its specific hazards, LNG storage tanks must maintain a safe distance from other equipment or spaces. Therefore, using LNG as fuel requires sufficient space on the ship for LNG fuel tank installation, which is a limitation for inland vessels due to space constraints.

For ships with different sailing ranges, the scenarios for using LNG as the sole fuel are as follows:

For a range of less than 200 km: The minimum applicable ship type for LNG is approximately 500 gross tons.

For a range of more than 500 km: The minimum applicable ship type for LNG is approximately 800 gross tons.

For a range of more than 1,000 km: The minimum applicable ship type for LNG is approximately 1,500 gross tons.

(2) Pure Electric Ships

Carbon Reduction Effect

Pure electric ships eliminate direct CO_2 emissions during operation, as they are

[59] China Classification Society (2023), Outlook for Low-Carbon Development in Shipping 2023.https://www.ccs.org.cn/ccswz/articleDetail?id=202312081257422748&columnId=202201100237247637

powered by electricity stored in batteries rather than burning fuel. This results in a significant reduction in carbon emissions, particularly in inland waterways where the carbon intensity of electricity can be relatively low if renewable energy sources are used. The carbon reduction effect is essentially 100%, as no emissions are generated directly from the propulsion system of the vessel.

Technical Status

The development of pure electric ships has progressed rapidly in recent years. The technology behind electric propulsion systems, battery storage, and electric charging infrastructure is advancing, but it is still at an early stage in terms of large-scale commercial application. There have been various small-scale and pilot projects, especially for inland waterways. For example, electric ferries, tugboats, and barges are being tested and put into service. However, challenges remain in terms of energy density, battery lifespan, and charging infrastructure.

Electric propulsion systems for ships rely on large-capacity batteries, often lithium-ion, which are integrated into the ship's design. These ships are designed to operate on relatively short routes where charging opportunities are available. For longer distances or larger vessels, the challenges of battery storage capacity and charging time remain a limitation. As battery technology improves, the range and applications of pure electric ships are expected to expand.

Applicable Scenarios

Pure electric ships are most suitable for short to medium routes, where the distance is manageable for the capacity of current battery technology. These vessels are often used in inland waterways, ports, and ferries. They are also ideal for applications with frequent stop-and-go operation, as they can recharge quickly during downtime. However, their use for longer ocean-going voyages is limited at present due to battery capacity and recharging challenges.

For inland waterways, electric ships are already in use for routes of up to 100 km or more, depending on the vessel size and battery capacity. They are suitable for smaller vessels with lower energy demands. The expansion of charging infrastructure is essential to supporting the widespread adoption of electric ships, and efforts are being made globally to develop port charging facilities and enable efficient charging networks.

In China, there are already pilot electric ships operating on inland routes, and the country is working on building up its infrastructure to support the broader adoption of electric vessels.

(3) Fuel cell ships

Carbon Reduction Effect

Currently, marine fuel cell ships include Solid Oxide Fuel Cells (SOFC) and Proton Exchange Membrane Fuel Cells (PEMFC). SOFCs can use hydrogen-rich fuels such as LNG, methanol, and ammonia. During the operation of fuel cell ships, there are no exhaust emissions, making them similar to pure electric ships in terms of their environmental benefits. This offers a significant reduction in carbon emissions and has considerable positive social and environmental impacts.

Technical Status

Fuel cell power is making breakthroughs towards the megawatt scale; however, the technology has certain drawbacks, including high operating temperatures (500–800°C), slow start-stop response, and poor impact resistance. Currently, fuel cells are limited by power density, technological maturity, and cost-effectiveness, making them unsuitable for use in large vessels and ocean-going ships.

Applicable Scenarios

Currently, hydrogen fuel cell ships are in the early stages of development, with existing hydrogen fuel cell-powered vessels mainly used for short-distance small passenger ferries. The main disadvantages of these vessels include immature technology, short range, and high construction costs.

Considering the technological and economic development trends, it is expected that in the near to medium term (before 2030), hydrogen fuel cell ships will primarily be suitable for short-distance small passenger ferries, dry bulk carriers, and container ships with a range of up to 200 kilometers and a weight of up to 2,000 tons. In the longer term (after 2030), as fuel cell technology matures and hydrogen storage density improves, the range of hydrogen fuel cell ships will increase, and their application will gradually expand to include the mainstream vessels in China's inland waterway network, covering various sizes and types of vessels such as passenger ships, dry bulk carriers, container ships, liquid bulk carriers, and river-sea transport ships.

(4) Methanol-Fueled Vessels

Carbon Reduction Effect

Methanol is a clean burning, safely stored and transported, and fully biodegradable fuel that can reduce CO_2 emissions by 10% to 15%. It produces no sulfur oxides and particulate matter and can reduce nitrogen oxide emissions by 80%[60]. However, methanol has less than half the energy density of diesel, so the fuel tank needs to be approximately doubled in size. Considering the full lifecycle, using green methanol can reduce emissions by 63% to 99%.

Technical Status

Gray methanol is primarily produced from coal, natural gas, etc., with sufficient production capacity, but the capacity for green methanol, which is produced from renewable carbon sources, biomass, and renewable electricity, is still relatively limited. On the equipment side, the industry is expanding the methanol engine product line, developing methanol fuel supply systems, and planning methanol refueling ports. In the context of lifecycle greenhouse gas emissions, green methanol can achieve medium- to long-term emission reduction goals for ships, and it will become one of the important alternative fuels for deep emission reductions in the maritime industry. The technology requirements for methanol-fueled vessels are similar to those for LNG-fueled vessels. The methanol fuel supply system is a critical piece of equipment that provides a continuous and stable fuel supply to methanol dual-fuel engines.

Applicable Scenarios

Currently, nearly 30 methanol-fueled vessels are in operation worldwide, with 24 of these being methanol transport vessels, and the remainder being car-passenger ferries, pilot boats, and container ships. As of November 2023, more than 220 new orders for methanol-powered vessels have been placed globally, including over 150 container ships, along with bulk carriers, tankers, offshore vessels, and car transport ships. With the improvement of standards and the maturation of technology, it is expected that in the near future (by 2025), methanol-fueled vessels will be suitable for domestic small and medium-sized (below 3,000 tons) dry bulk carriers, container ships, liquid bulk carriers, passenger ships, and China-to-sea direct vessels. However, due to the low energy density of methanol fuel, the increased need for fuel storage, some small vessels (under 300 tons) may face challenges in layout. In the medium to long term (after 2025), as technology and equipment mature and supporting infrastructure improves, the range and applicability of methanol-powered vessels will expand to include mainstream domestic inland ships of various sizes, including passenger ships, dry bulk carriers, container ships, liquid bulk carriers, and China-to-sea direct vessels.

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[60] WU Xianfa. The present situation of green methanol as shipping decarbonized fuel and the analysis of its supply chain [J]. *Tianjin of Navigation*, 2023(03):74-78.

(5) Ammonia-fueled vessels

Carbon Reduction Effect

Ammonia is a compound of nitrogen and hydrogen. Since it contains no carbon, it does not emit any carbon dioxide when used as fuel in internal combustion engines, making it a true zero-carbon fuel.

Technology Status

Currently, the industry is developing ammonia-fueled vessels and supporting equipment. Some ship owners have already placed orders for the world's first ammonia-fueled bulk carriers. As for ammonia engines, recent manufacturers have introduced ammonia-fueled medium-speed engine products, with low-speed engine products expected around 2025. Currently, ammonia is primarily synthesized through the Haber-Bosch process, with raw materials such as natural gas, coal (or coke), and heavy oil. Compared to other fuels, ammonia has the following advantages:

- Environmental Benefits: Ammonia is carbon-free and does not produce carbon dioxide during combustion in engines, significantly reducing greenhouse gas emissions.
- Abundant Sources and Mature Preparation Technology: Ammonia can be produced using renewable energy sources like wind and solar power.
- High Volumetric Energy Density: In its liquid form, ammonia generates almost 50% more heat than hydrogen fuel per unit volume.
- Storage and Transport: Ammonia can be stored in pressurized tanks at about 1 MPa or in low-temperature tanks at about -34°C. This helps improve ship space utilization and lowers transportation costs. When used in liquid form, ammonia's storage and transportation systems are simpler compared to other fuels, requiring only minor modifications to conventional internal combustion engines, such as adjusting the compression ratio and replacing corrosion-resistant pipelines, significantly reducing operational costs[61].
  However, for widespread application, ammonia still has some disadvantages:
- Toxicity: Ammonia is toxic, and its compounds have a pungent odor. Even low concentrations of ammonia can irritate the eyes, nose, and throat.
- Corrosion: When ammonia comes into contact with moisture in the air, it forms ammonia water, which can corrode the ship's hull.

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[61] ZHANG Yunfan, XIAO Qingsong, HU Zhiqiang. High-Tech Frontier | The Arrival of Ammonia-Fueled Ships. 2024.

- Safety Concerns: In a combustible environment, ammonia can exacerbate the consequences of an explosion.

Applicable Scenarios

The application of liquid ammonia in ships is still in the early research phase, and there are no applications on ships in China yet. However, based solely on the properties of ammonia gas, ammonia is suitable for all ship types.

Due to the requirements for ship endurance, ammonia is stored in its liquid form on ships after being liquefied under low temperatures or high pressure. In terms of energy content, liquid ammonia has about 0.44 times the energy value of diesel for the same mass. The shape of ammonia storage tanks is similar to LNG tanks, which are oval-shaped. Since ammonia is toxic and has other dangerous properties, the storage tanks must maintain a safe distance from other equipment and spaces. Therefore, ships using ammonia as fuel must have enough space to accommodate the ammonia fuel tank. The larger the ship's main dimensions, the fewer the restrictions. Based on the analysis, the following tonnage conditions apply to ships using liquid ammonia as fuel:

- For routes within 200 kilometers: The minimum applicable ship type is about 1,000 gross tons.
- For routes over 500 kilometers: The minimum applicable ship type is about 2,000 gross tons.
- For routes over 800 kilometers: The minimum applicable ship type is about 3,000 gross tons.

Table 8 Comparison of the Current Status of Low-Carbon/Zero-Carbon Power Development

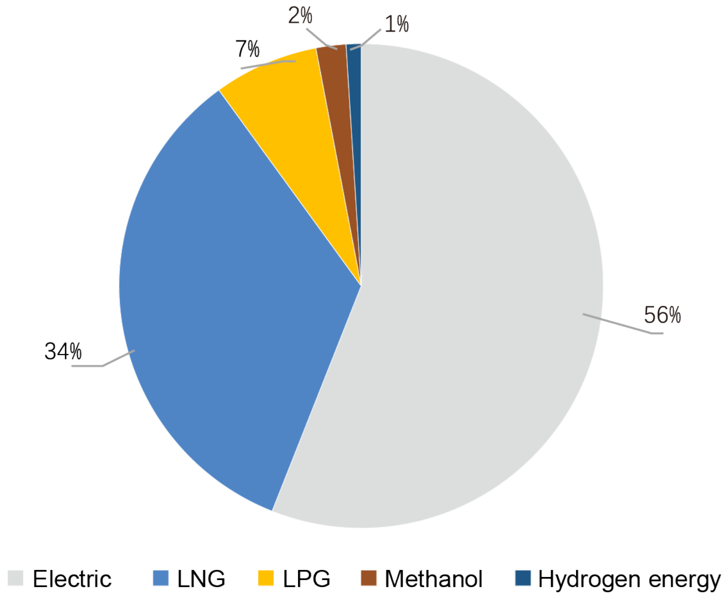
Low Carbon/ Zero Carbon Power	Technical Maturity	Emission Reduction Effects	Standards & Regulations	Endurance	Economic Efficiency	Supporting Facilities
LNG	Mature	Fair	Relatively complete	Good	Common	Relatively complete
Pure electricity	Relatively mature	Zero emission	Preliminary establish	Below average	Poor	Preliminary establish
Fuel cell	Immature	Zero emission	None	Below average	Poor	None
Methanol	Common	Common	None	Fair	Fair	None
Ammonia	Immature	Zero emission	None	Common	-	None

The battery pack propulsion technology has lower power in a single battery compartment and requires frequent charging or battery replacement. It currently cannot meet the power and endurance needs of larger-tonnage vessels, so it will be prioritized for use in small-tonnage vessels before 2025, and gradually promoted to larger-tonnage vessels from 2026 to 2035. Methanol power technology has low maturity, its safety needs further validation, and refueling stations are required for fueling operations. Currently, the fueling infrastructure is not well-developed, and its power performance is poor. Before 2025, it will be conditionally applicable to bulk carriers and container ships on the downstream section of the Yangtze River; from 2026 to 2035, after the technology matures and fueling infrastructure is improved, it will be applicable to vessels on the entire Yangtze River. Ammonia fuel power technology, due to its low maturity, high initial investment, and poor power performance, will not be applicable to Yangtze River vessels before 2025; however, as the technology gradually matures, it is expected to be applicable to small-tonnage vessels in the mid to long term (2026-2035).

16. How is the electrification development of inland river vessels in China?

EVTank, the EV Economics Research Institute, and the China Battery Industry Research Institute jointly released the "China Electric Vessel Industry Development White Paper (2024)[62]." According to EVTank statistics, by the end of 2023, the number of electric vessels in China exceeded 700, with more than 200 new vessels added that year. This has driven the shipment of lithium batteries for vessels to reach 0.61 GWh, marking an 80% year-on-year growth, making it one of the fastest-growing sectors in the lithium battery downstream application field. The white paper stated that the rapid development of electric vessels and battery-swapping technology will drive the demand for lithium batteries. It is expected that by 2025, the demand for lithium batteries for vessels will reach 1.4 GWh, and by 2030, it will reach 21.9 GWh. EVTank predicts that by 2025, the number of electric vessels in China will reach 1,520, and by 2030, it will exceed 10,000 vessels[63].

Globally, electric vessels account for about 56% of the green vessels, with more than 1,000 vessels using low-carbon/zero-carbon power in 2022.

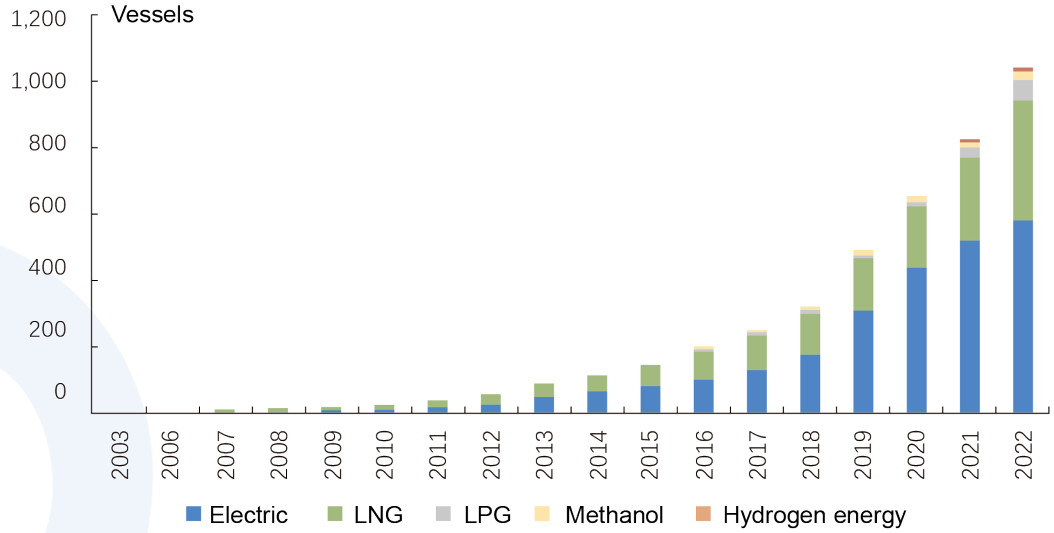


Source: Sealand Securities, "In-Depth Report on the Electric Ship Industry: The Era of Green and Intelligent Development Has Arrived, Sailing Toward a Billion-Dollar Electrification Market"

Figure 25 Global Green Ship Structure in 2022

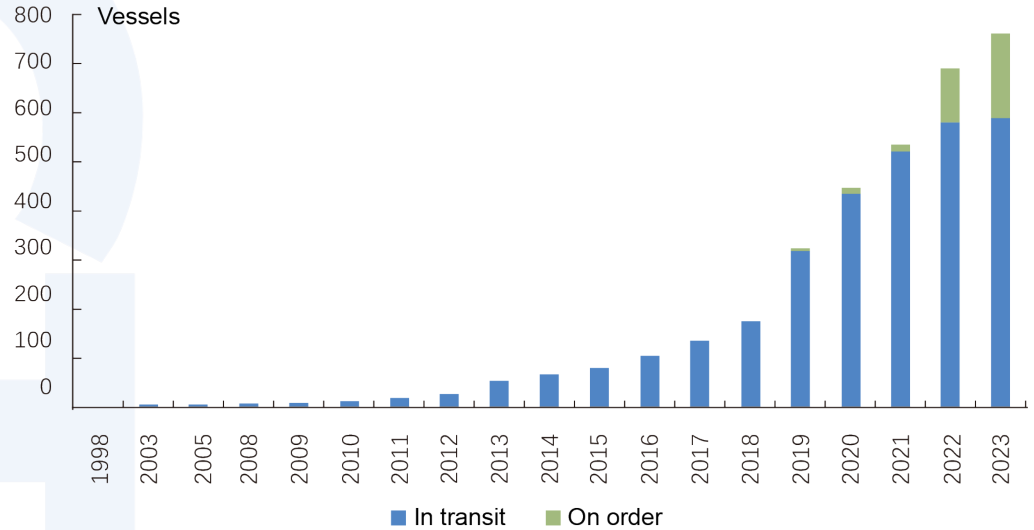
[62] 2024. IVI Economic Research Institute. EVTank: Lithium Battery Shipments for Electric Ships in China Reached 0.61 GWh in 2023, with a Year-on-Year Increase of 87.1%. 2024.

[63] Data Source: the industry research report titled "In-depth Report on the Electric Ship Industry: The Electric Development of Ships is About to Enter a Booming Period" published by Guohai Securities.



Source: Sealand Securities, "In-Depth Report on the Electric Ship Industry: The Era of Green and Intelligent Development Has Arrived, Sailing Toward a Billion-Dollar Electrification Market"

Figure 26 Number of Ships Using Low-Carbon/Zero-Carbon Power Globally

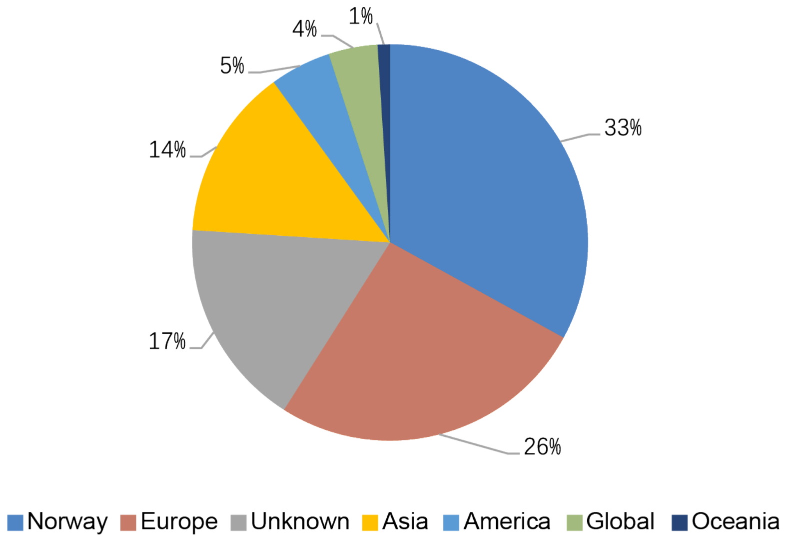


Source: Sealand Securities, "In-Depth Report on the Electric Ship Industry: The Era of Green and Intelligent Development Has Arrived, Sailing Toward a Billion-Dollar Electrification Market"

Figure 27 Number of Electric Ships Worldwide (In Operation + Under Construction)

In 2022, the total number of electric ships globally, including those in operation and under construction, approached 800[64]. Among these, Norway accounted for 33%, Europe (excluding Norway) for 26%, and Asia for 14%.

[64] Data Source: Guohai Securities. In-depth Report on the Electric Ship Industry: The Trend of Green Intelligence Has Arrived, Heading for a Hundred Billion Blue Ocean of Electrification. 2023.



Source: Sealand Securities, "In-Depth Report on the Electric Ship Industry: The Era of Green and Intelligent Development Has Arrived, Sailing Toward a Billion-Dollar Electrification Market"

Figure 28 Regional Distribution of Global Electric Ships in 2022

The development of electric ships for inland waterways in China faces challenges in several areas. Technological upgrades: The energy density of ship power batteries remains low. Currently, lithium iron phosphate (LFP) batteries and ternary lithium batteries achieve an energy density of 200–300 Wh/kg, which limits the cruising range of ships due to space constraints. Moreover, the lack of sufficient charging infrastructure for ships hinders the wider adoption of pure battery-powered vessels. Economic feasibility: The initial investment cost of electric ships is high. Pure electric ships primarily rely on LFP or ternary lithium batteries as their energy source. The relatively high market price of these batteries leads to significant upfront costs. Shore power infrastructure requires the construction of charging and battery-swapping stations. The combined costs of these elements impact the economic feasibility of investment projects[65]. Safety concerns: Ship batteries typically have large capacities, ranging from several thousand kilowatt-hours to nearly 10,000 kilowatt-hours. Under the current charging rate, charging times are long. Even with high-voltage charging and low-voltage supplementary charging methods used in some industry projects, recharging close to 10,000 kilowatt-hours can still take over 10 hours. Additionally, due to inconsistencies in battery cells, excessive charge/discharge rates (current divided by battery capacity) can accelerate battery degradation, shorten battery lifespan, and even pose safety risks[65].

[65] WANG Libo. Study on the Current Situation and Countermeasures of the Development of China's Electric Ship Industry [J]. *China Maritime Safety*, 2022(8):4.

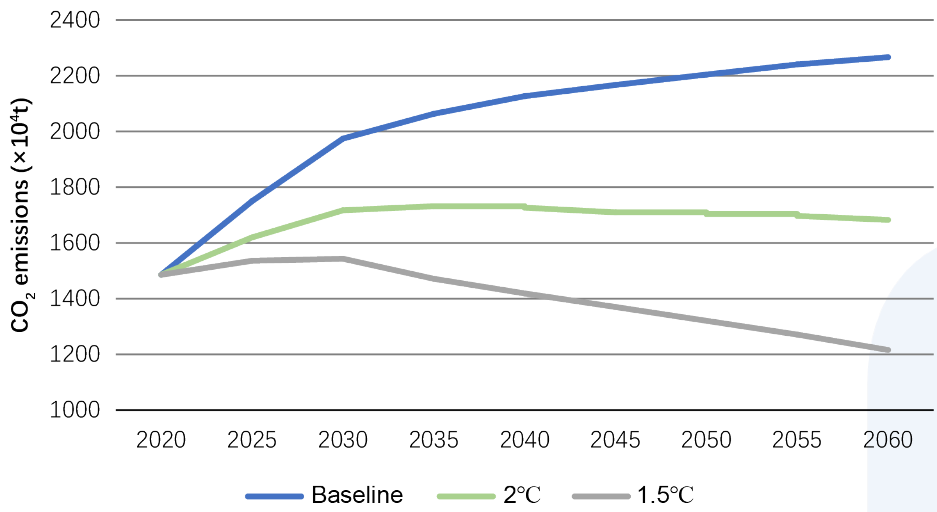
17. What is the medium- and long-term emission reduction scenario analysis for inland waterway transportation in China?

In the 2021 Green Transportation 14th Five-Year Development Plan released by the Ministry of Transport, a specific target for the 14th Five-Year Plan is to reduce CO_2 emissions per unit transport turnover of operational ships, i.e., the energy consumption intensity of ships, by 3.5% compared to 2020. Similarly, the 2021 Action Plan for Carbon Peaking Before 2030, issued by the State Council, sets a goal to reduce carbon emission intensity per unit transport turnover of operational vehicles by 9.5% by 2030 compared to 2020.

In 2023, the IMO Strategy for the Reduction of Greenhouse Gas Emissions from Ships updated its quantitative targets for reducing greenhouse gas emissions in shipping. The goal is to reduce the average CO_2 emissions per unit of transport activity by at least 40% by 2030 compared to 2008 and to achieve net-zero greenhouse gas emissions around or before 2050.

To describe the carbon emission trends of inland ships, quantify the combined benefits of various carbon reduction measures, and explore potential carbon reduction pathways for inland waterway transportation, the Ministry of Transport released the Research on Medium- and Long-Term Low-Carbon Development Pathways for Inland Waterway Transportation in China. This study outlines three carbon reduction scenarios: the Baseline Scenario, the 2°C Scenario (aligned with the global temperature rise control target of 2°C), and the 1.5°C Scenario (aligned with the 1.5°C temperature rise control target).

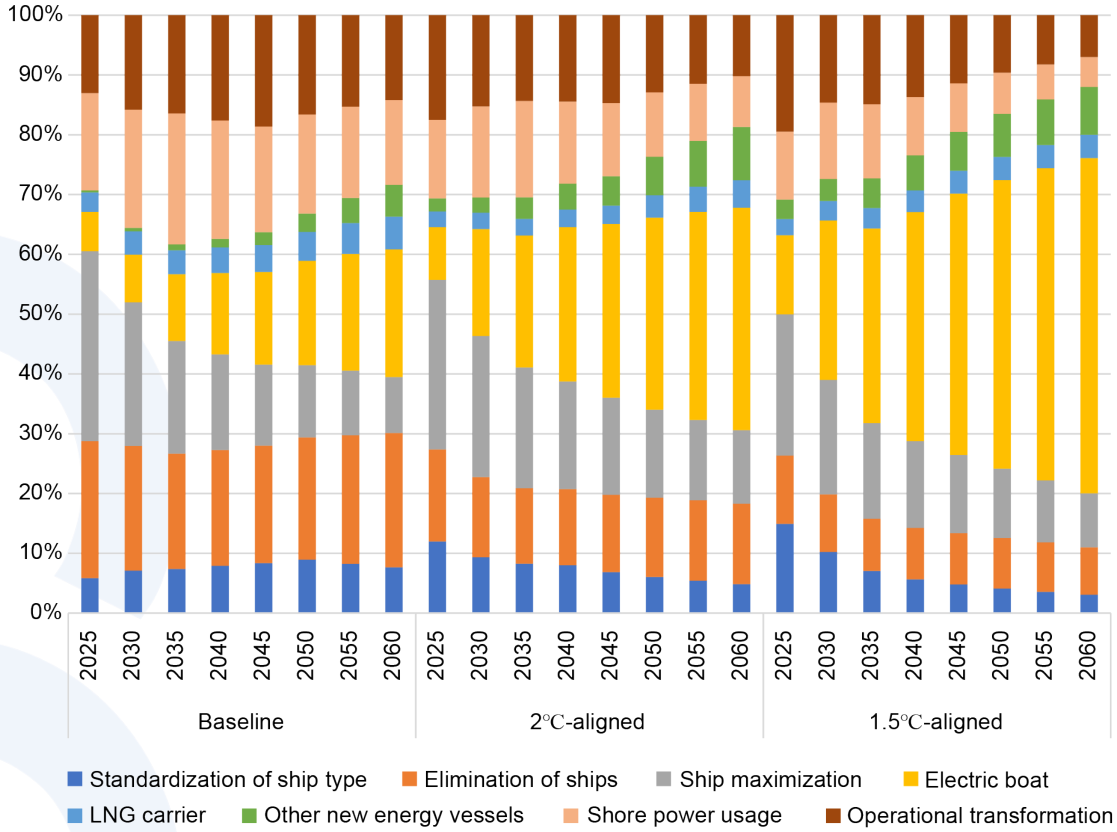
The Baseline Scenario primarily focuses on measures such as phasing out older vessels, transitioning to larger ships, implementing shore power applications, and adopting operational energy efficiency strategies, supplemented by a lower proportion of electric and other low-carbon fuel ships. The 2°C Scenario and 1.5°C Scenario are built upon the baseline by increasing the proportion of electric and low-carbon fuel ships.



Source: China Waterborne Transport Research Institute, Ministry of Transport, "Research on Medium- and Long-Term Low-Carbon Development Pathways for Inland Waterway Transportation in China"

Figure 29 Projected CO_2 Emissions from China's Inland Waterway Transportation under Different Carbon Reduction Pathways (2020–2060)

The scenario analysis results are shown in Figure 29. Under the Baseline Scenario, CO_2 emissions grow rapidly from 2020 to 2030, reaching 18.74 million tons in 2030. Although carbon emission intensity decreases after 2030, the continued growth in cargo turnover results in a slower rate of increase in CO_2 emissions, which stabilizes at a growth trend, reaching 22.66 million tons by 2060.Under the 2°C Scenario, with the implementation of various carbon reduction measures, CO_2 emissions reach 17.17 million tons by 2030 and then begin to gradually decline, reaching 16.82 million tons by 2060.Under the 1.5°C Scenario, with the adoption of more intensive carbon reduction measures, CO_2 emissions reach 15.43 million tons by 2030 and then sharply decline, reaching 12.15 million tons by 2060.



Source: China Waterborne Transport Research Institute, Ministry of Transport, "Research on Medium- and Long-Term Low-Carbon Development Pathways for Inland Waterway Transportation in China"

Figure 30 Contribution Proportion of Various Carbon Reduction Measures to CO_2 Emission Reductions in China (2025–2060)

As shown in Figure 30, sourced from the *China Waterborne Transport Research Institute, Ministry of Transport, "Research on Medium- and Long-Term Low-Carbon Development Pathways for Inland Waterway Transportation in China"*, the contribution of various carbon reduction measures to CO_2 emission reductions is outlined.

An increase in the proportion of electric ships significantly contributes to CO_2 reduction, especially under the 1.5°C scenario, where their contribution is the most notable. Ship enlargement will continue to provide significant CO_2 reduction in the next five years, but its contribution diminishes over time as the trend toward larger ships becomes unsustainable. Ship retirements, though less influenced by emission reduction scenarios, still make a substantial contribution to CO_2 reduction under the Baseline Scenario.

In comparison to China's related reduction targets, predictions of ship energy consumption intensity under the above scenarios show that by 2025, energy intensity decreases by 6.11%, 9.05%, and 12.08% under the Baseline, 2°C, and 1.5°C scenarios, respectively, exceeding the planned targets. By 2030, energy intensity decreases by 10.02%, 15.21%, and 20.41%, meeting the targets set in the action plan.

In comparison to international reduction targets, estimates across scenarios indicate that by 2030, ship energy consumption intensity could decrease by over 70% compared to 2008. However, achieving net-zero emissions by 2050 remains unattainable.

To achieve inland ship carbon reduction goals, it is essential to integrate technical, operational, and innovative solutions tailored for ships. The following phased implementation is recommended for carbon reduction in China's inland ships:

- Short-term: Focus on increasing shore power usage, accelerating electric ship pilots, and promoting ship standardization.
- Mid-term: Emphasize the use of new-energy ships, actively improve the operational energy efficiency of existing ships, accelerate the phasing out of older ships, and further enhance ship standardization.
- Long-term: Prioritize reducing the carbon intensity of fuels and strengthen policy and technical support for electric ships and other new energy applications.

18. What is the carbon reduction potential of coastal shipping in China?

To quantify the carbon reduction potential of various measures mentioned above and explore potential carbon reduction pathways for coastal shipping, the ICCT study defined three scenarios for carbon reduction in coastal shipping: the Baseline Scenario, the 2°C Alignment Scenario (aligned with the global goal of limiting warming to 2°C), and the 1.5°C Alignment Scenario (aligned with the goal of limiting warming to 1.5°C). The Baseline Scenario primarily relies on the high-quality development of coastal shipping and improvements in ship energy efficiency as the main carbon reduction measures, while the 2°C and 1.5°C scenarios build on the Baseline Scenario by incorporating additional low-carbon fuel policies[66].

As shown in Figure 31, under the Baseline Scenario, if no policies or measures are introduced to reduce CO_2 emissions from China's coastal fleet using low-

[66] Mao X, Meng Z. Decarbonizing China's coastal shipping: the role of fuel efficiency and low carbon fuels. The International Council on Clean Transportation, 2022.

carbon fuels, the CO_2 emissions from coastal ships will more than triple due to growing demand for maritime transport, rising from 45 million tons in 2019 to 162 million tons in 2060.

By implementing mandatory energy efficiency standards and low-carbon fuel regulations, the 2°C Scenario and 1.5°C Scenario project CO_2 reductions of 56% and 83% by 2060, respectively, compared to the 2019 baseline. In both scenarios, the total fleet's CO_2 emissions are expected to peak before 2040

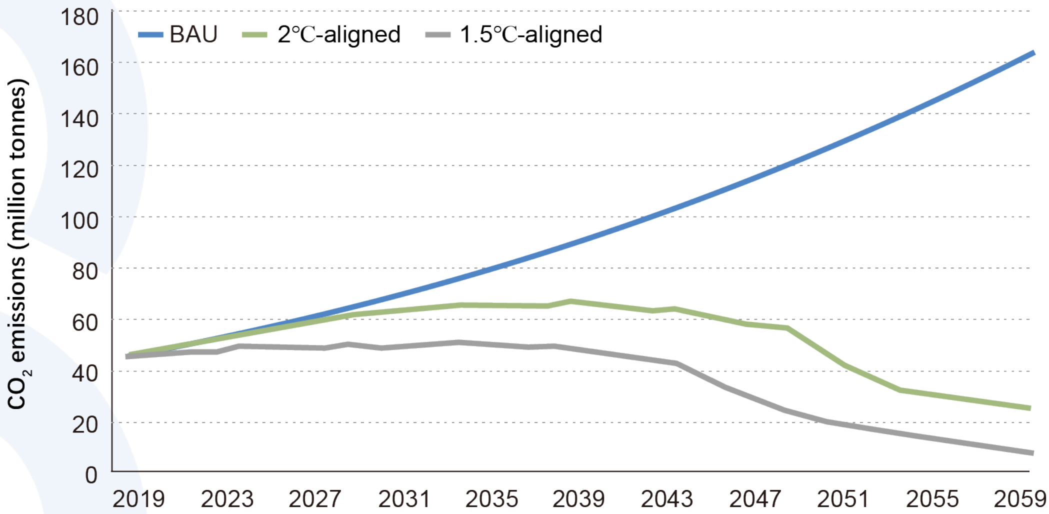


Figure 31 Projected CO_2 Emissions and Carbon Reduction Pathways for China's Coastal Shipping (2019–2060)

Under the 1.5°C Scenario, the carbon reduction potential of various measures is further broken down, as shown in Figure 32. Energy efficiency improvements remain one of the key measures for reducing carbon emissions from ships. As the fleet continues to be updated, the carbon reduction potential associated with energy efficiency policies will gradually be realized.

Although transitioning to low-carbon fuels poses a significant challenge for the entire shipping industry, gradually increasing the proportion of low-carbon fuel usage will be one of the most important measures for reducing ship emissions. This transition has the potential to achieve substantial CO_2 reductions by 2060 and guide the shipping industry toward a truly low-carbon or even zero-carbon future.

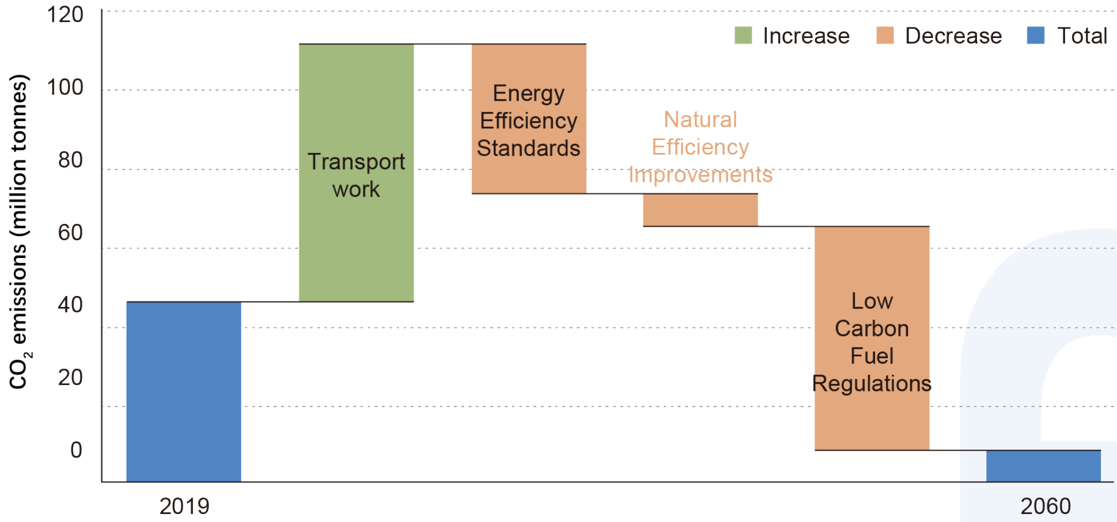


Figure 32 Carbon Reduction Potential of Various Measures Under the 1.5°C Scenario

Introducing regulations for low-carbon fuels as early as possible will facilitate a smooth transition for China's coastal shipping industry toward a low-carbon future. Delaying the implementation of low-carbon fuel regulations until 2046 would pose significant challenges for the industry. In the model simulation, the implementation of low-carbon fuel regulations was postponed to 2046 (as shown in Figure 33), leaving only 15 years for low-carbon fuels to help the shipping sector achieve its 2060 emission reduction targets. Under both delayed implementation scenarios, the peak CO_2 emissions from the shipping sector would also be postponed to around 2045.

- In the 2°C delayed implementation scenario, the shipping sector would need to reduce the carbon intensity of transportation fuels by 71% cumulatively over 15 years (relative to the 2019 baseline).
- In the 1.5°C delayed implementation scenario, the sector would need to achieve a cumulative reduction of 88**%** in fuel carbon intensity over the same period. These are undoubtedly daunting and high-intensity emission reduction requirements, presenting significant challenges for the industry.

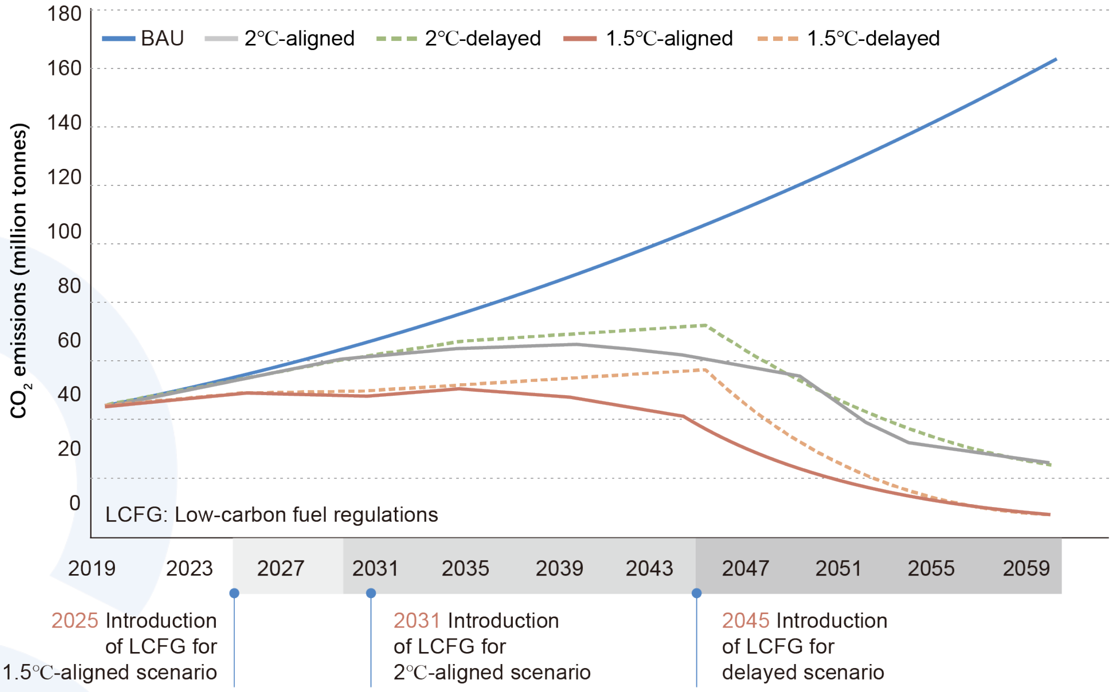


Figure 33 Impact of Delayed Implementation of Low-Carbon Fuel Regulations on Meeting the 2°C and 1.5°C Scenarios

To achieve the decarbonization goals of China's domestic coastal fleet, the introduction of mandatory energy efficiency standards and low-carbon fuel regulations is critical. The implementation of low-carbon fuel regulations should occur no later than 2030 to allow sufficient time for the development of related industries and technologies. If the implementation is delayed until after the completion of the mandatory energy efficiency standards cycle (2046), it will be extremely difficult to achieve the decarbonization targets for the shipping sector.

19. How can international ports achieve green and low-carbon development? What are the lessons that can be learned?

Ports, as critical nodes in the global supply chain, hold an undeniable importance. According to research, port-related carbon emissions account for approximately 3% [67] of global CO_2 emissions. Decarbonizing ports will significantly contribute to helping countries around the world meet their climate commitments and targets.

Port of Rotterdam, Netherlands[68]

The Port of Rotterdam, the largest port in Europe, spans a total area of 12,470 hectares. In 2023, it handled 27,886 ocean-going vessels and 89,175 inland vessels.

The Port of Rotterdam has established greenhouse gas emission targets: a 55% reduction in carbon emissions from the port and industrial complex by 2030 compared to 1990 levels[69] and achieving net-zero emissions by 2050. To fulfill its climate commitments, the port is implementing a strategy based on four key pillars:

- Pillar 1: Energy Efficiency and Infrastructure. This includes utilizing waste heat for building heating, carbon capture and storage (CCS), laying pipelines for green and low-carbon fuels, and upgrading the power grid for electrification.
- Pillar 2: New Energy Systems. This involves using low-carbon energy sources such as wind, solar, electricity, and green hydrogen for energy supply. By 2050, Rotterdam plans to produce 2 million tons of hydrogen locally and import an additional 18 million tons.
- Pillar 3: New Raw Materials and Fuel Systems. The port aims to replace fossil fuels and raw materials with alternatives such as biomass, material recycling, and green hydrogen.
- Pillar 4: Sustainable Transport. Through collaboration with stakeholders in the supply chain, the port seeks to improve energy efficiency, install shore power, provide sustainable fuels, and establish international alliances to achieve carbon-neutral transport.

The Port of Rotterdam made significant progress in carbon reduction in 2023,

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[67] International Transport Forum (2021), ITF Transport Outlook 2021. https://www.itf-oecd.org/itf-transport-outlook-2021

[68] Data Source: The *Highlights Annual Report 2023* published by the Port Authority of Rotterdam.

achieving a 10% decrease in emissions compared to 2022, equivalent to 2.2 million tons of CO_2. For the first time, its CO_2 emissions fell below 1990 levels[69]. Key measures included:

- Scope 1 Emissions. Using biomass-based fuels for operating ships, and replacing fossil fuel-powered vehicles with electric vehicles. These measures resulted in 57% and 69% reductions in Scope 1 emissions, respectively (using 2019 as the baseline).
- Scope 2 Emissions: Purchasing green electricity, which led to a 33% reduction in Scope 2 emissions compared to 2019.
- Scope 3 Emissions: Reducing air travel, promoting hybrid work models, and encouraging suppliers to use electric equipment and clean fuels. These efforts reduced Scope 3 emissions by 53%, 55%, and 21%, respectively, compared to 2019 levels.

United States Ports

Most decarbonization efforts at U.S. ports focus on the electrification of cargo handling equipment. This is partly because carbon emissions from port service vessels represent a small proportion, and partly because trucks, trains, and ships accessing the ports are typically not under the guidance or control of the port authorities.

- Developing Greenhouse Gas (GHG) and Pollutant Emission Inventories. Creating GHG and pollutant emission inventories is crucial for port decarbonization. These inventories help identify key areas for action and track progress and effectiveness. While the inventory does not need to be exhaustive, it should include emissions from the following categories: ocean-going vessels, port service vessels, cargo handling equipment, vehicles, trains, and facilities.
- Implementing Carbon Reduction Measures for Port Logistics. Truck Emissions: Trucks are the largest source of GHG emissions among port vehicles [70]. However, since ports do not control these vehicles, reduction efforts depend on policies and incentives from local and state governments. For instance, California's Port of Long Beach introduced the Clean Truck Program in 2008 to reduce truck emissions. Since its full implementation in 2012, truck emissions have decreased by more than

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[69] Data Source: *10% decrease in port of Rotterdam CO_2 emissions in 2023* published by the Port Authority of Rotterdam

[70] Port of Long Beach (2024), Clean Trucks Program. https://polb.com/environment/clean-trucks/#program-details

90%. Cargo Handling Equipment: Rubber-tired gantry (RTG) cranes are common cargo handling equipment in ports. Many U.S. ports are retrofitting RTG cranes with electric or hybrid systems. Studies show71 that electric RTG cranes save 86.6% of energy consumption and reduce carbon emissions by 67.79% compared to traditional cranes. Additionally, U.S. ports have fully electrified ship-to-shore cranes and are promoting fuel cell forklifts to further reduce carbon emissions from cargo handling equipment.

- Enhancing Port Energy Systems. Shore power systems installed at U.S. ports are generally classified into high-voltage and low-voltage systems. High-voltage systems (supply voltage >1kV) provide power to large vessels, such as cruise ships, container ships, and LNG carriers. Low-voltage systems (supply voltage <1kV) supply power to smaller vessels, such as fishing boats and tugboats.

Ports typically install renewable energy sources to meet around 10%72 of their electricity needs. Solar power, which can be installed on rooftops or parking lots, is a preferred clean energy option for ports. Wind power installations are rare within port jurisdictions. Some ports are leveraging renewable energy generation and storage facilities to build microgrids, which not only reduce carbon emissions but also enhance the resilience of their electrical systems.

South Korean Ports

Port of Busan[73]: As South Korea's largest port, the Port of Busan handles 77% of the country's container import/export cargo and 97% of its transshipment cargo. According to 2021 statistics, the port emitted 2,221,131 tCO_2eq, with 87.3% of emissions coming from ships and trucks and 12.7% from equipment. In 2022, the Port of Busan implemented the following measures to reduce its carbon emissions:

- In April 2022, the port announced plans to develop the "2050 Busan Port Carbon Neutral Comprehensive Plan", targeting a 40% reduction in emissions by 2030 compared to 2018 levels.

- Retrofitted 583 diesel-powered tractors to gas-powered vehicles and

[71] Yi-Chih Yang, Wei-Min Chang. Impacts of electric rubber-tired gantries on green port performance. Research in Transportation Business & Management, 2013.
[72] American Bureau of Shipping (2024), Port Decarbonization Survey: Trends and Lessons Learned. https://aapa.cms-plus.com/files/appa-port-decarb-survey-publication.pdf
[73] Data Source: 2022 Busan Port Authority Sustainability Report published by the Port of Busan

added DPF filters.

- Implemented port vessel speed reductions, with 9,796 vessels participating, achieving a participation rate of 78.2%.
- Upgraded lighting to LED, saving 6,290 MWh of electricity and reducing emissions by 2,890 tCO2eq.
- Used 6,290 MWh of shore power.

Port of Ulsan[74]: As South Korea's third-largest port, the Port of Ulsan has developed the "2050 Ulsan Port Carbon Neutral Roadmap", aiming for a 30% reduction in emissions by 2030, 50% by 2040, and 100% by 2050. In 2021, Ulsan was designated as South Korea's hydrogen energy port and has been building a hydrogen supply chain while advancing the construction of green terminals associated with hydrogen businesses. Key decarbonization measures implemented in 2021 included:

- Carbon reduction of approximately 1,400 tons through LED lighting upgrades, the installation of solar panels, and adjustments to air conditioning and heating temperatures.
- Fuel consumption reduction of 68.9% by procuring and using environmentally friendly vehicles.
- Encouraged low-speed approaches for incoming ships, with 1,588 vessels participating, resulting in a reduction of 11,347 tons of CO2 emissions.
- Promoted shore power usage, achieving a 517-ton reduction in greenhouse gas emissions.

Singapore Ports

Port of Singapore: As one of the busiest ports in the world, the Port of Singapore handled a container throughput of 3,730 TEU[75] in 2022. The port aims to reduce carbon emissions by 60% by 2030 compared to 2005 levels and achieve net-zero emissions by 2050. The port's two operators, PSAC and JPPL, have implemented different decarbonization measures based on their specific operations.

[74] Data Source: *2022 UPA Sustainability Report* published by the Port of Busan

[75] Data Source: *Charting an Innovative and Sustainable Future for Maritime Singapore* published by Maritime and Port Authority of Singapore

PSAC[76]: PSAC has set a carbon reduction target of 50% by 2030, 75% by 2040, and net-zero by 2050 compared to 2019 levels. Key measures to achieve its 2030 carbon reduction goal include:

- Greening Equipment: By 2030, PSAC plans to retrofit 210 diesel yard cranes to LNG-powered and fully electrify the equipment at Tuas Port.
- Using Green Electricity: PSAC is reducing Scope 2 GHG emissions by installing rooftop solar photovoltaic (PV) systems. As of 2022, its solar PV capacity has reached 9.4 MW.

JPPL[77]: JPPL has set more ambitious carbon reduction targets, aiming for a 62% reduction by 2030 (compared to 2005 levels) and net-zero emissions by 2040. To achieve these goals, JPPL has adopted three main strategies: electrification, solar PV, and low-carbon fuels.

- Electrification: Replacing truck transport with crane and conveyor belt systems, which is expected to reduce carbon emissions by 18,900 tCO_2e; Electrifying forklifts, which is estimated to be cut to 910 tCO_2e annually.
- Solar PV: Installed 9.56 MW of solar PV in 2016; Plans to further expand PV installations to meet 75% of its electricity needs.
- Low-Carbon Fuels: Using low-carbon fuels for power generation to meet the remaining 25% of electricity demand. For example, JPPL is developing a low-carbon hydrogen supply chain in Singapore and using fuel cell technology for power generation.

Indian Ports

In May 2023, India introduced the "Green Port Guidelines", aiming to reduce carbon emissions per ton of cargo by 30% by 2030 (compared to the 2022-2023 fiscal year) [78] and by 70% by 2047. Key focus areas include:

- Greening Initiatives: By 2030, green areas will cover over 20% of port areas. By 2047, this coverage will increase to 33% or more.
- Electrification of Port Equipment/Machinery: Achieve 50% electrification by 2030. Increase to over 90% electrification by 2047.

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[76] Data Source: *Sustainability at PSA Singapore 2022* published by Maritime and Port Authority of Singapore

[77] Data Source: *Environmental Sustainability Report* published by Jurong Port

[78] Data Source: *"Harit Sagar" Green Port Guidelines* published by Ministry of Ports, Shipping and Waterways of India

- Use of Low-Carbon and Zero-Carbon Fuels for Port Service Vessels: Retrofit port service vessels and gradually adopt green ammonia, green hydrogen (fuel cells), and green methanol.
- Utilization of Renewable Energy: Renewable energy should account for over 60% of energy use by 2030. Increase to 90% by 2047.
- Shore Power Implementation: By 2023, provide shore power to port service vessels. By 2024, extend this to Coast Guard, Navy, and small coastal vessels. By 2025, include EXIM (export-import) vessels.

By analyzing the emission reduction measures of various ports, it becomes evident that different types of ports have unique characteristics and focal points in their approaches. Large integrated ports, such as the Port of Rotterdam and Port of Singapore, typically adopt comprehensive emission reduction measures, including energy efficiency optimization, the use of low-carbon energy, equipment upgrades, and the promotion of shore power. These ports, with diverse facilities and extensive business operations, require all-encompassing strategies to achieve carbon reductions. Specialized ports, such as South Korea's Port of Busan, which primarily handles containerized import and export cargo, focus their emission reduction measures on the retrofitting of specific equipment and transport tools, such as converting vehicles to gas-powered and promoting the use of shore power. These targeted equipment modifications and operational optimizations significantly reduce emissions from specific sources. Regional ports in the United States primarily concentrate on the electrification of cargo handling equipment and localized energy system improvements, gradually reducing emissions in specific areas through targeted equipment electrification and the use of clean energy. This classification and analysis provide actionable insights for other ports, enabling them to develop targeted emission reduction strategies tailored to their unique characteristics, thereby achieving optimal carbon reduction outcomes.

20. What measures has China implemented for green and low-carbon development at its ports? What progress has been made[79]?

(1) Progress in the Construction and Utilization of Shore Power at Ports

Docked transport vessels are the largest contributors to NOx and greenhouse gas emissions at ports. Utilizing shore power is an effective way to reduce air pollutants and greenhouse gas emissions during a vessel's stay at the port. Countries such as China, the European Union, and the United States have implemented various measures to promote the use of shore power by docked vessels, and there is a growing consensus on its importance. Currently, China has achieved significant progress in the construction of shore power facilities at major ports. However, challenges remain in increasing the willingness of shipping companies to use shore power and accelerating the installation rate of shore power reception facilities on vessels. Addressing these issues is crucial to improving the overall utilization rate of shore power.

In recent years, shore power facilities at most ports have become more complete, and the coverage rate of shore power has further improved. According to incomplete statistics, as of 2022, the shore power coverage rate for five types of specialized berths has reached 100% in seven coastal ports (Qingdao, Tianjin, Huanghua, Zhanjiang, Yancheng, Zhuhai, and Yangpu) and 21 inland ports. The shore power supply capacity of major ports has reached an internationally leading level, providing a solid foundation and necessary facility conditions for docked ships to use shore power.

There is a significant difference in the progress of shore power usage between coastal ports and inland ports.

Inland ports have shown more active progress in using shore power for docked ships. In recent years, driven by relevant policies and regulations within the Yangtze River Economic Belt, key factors limiting the use of shore power—such as low installation rates of ship shore power reception facilities, non-standardized shore power interfaces between ports and ships, and the lack of penalties for non-compliance with shore power usage—have been effectively addressed. As a result, the use of shore power along the Yangtze River has significantly increased. In 2023, the shore power usage in the Yangtze River Economic Belt reached 120 million kilowatt-hours, a year-on-year growth of 66%, achieving the "14th Five-Year Plan" goal of exceeding 100 million kilowatt-hours

[79] Citing the series of reports titled "Blue Port Pioneer" by the Clean Air Asia.

more than two years ahead of schedule[80].

Regarding the installation rate of shore power reception facilities on ships, thanks to the implementation of the *Plan for Promoting the Retrofit of Shore Power Reception Systems on Transport Vessels in the Yangtze River Economic Belt*, the retrofitting of shore power systems for ships along the Yangtze River has steadily advanced. By the end of 2023, a total of nearly 14,000 transport vessels across 11 provinces and cities within the Yangtze River Economic Belt had completed shore power facility upgrades[81].

As for the issue of non-standardized shore power interfaces between ports and ships, the *Notice on Further Promoting the Use of Shore Power by Ships Docking in the Yangtze River Economic Belt* specified that existing low-voltage shore power facility connectors at terminals and on ships that do not meet national standards or technical rules for statutory ship inspections must be upgraded by the end of June 2022. The problem of inconsistent inland shore power interfaces has now been largely resolved.

Regarding the lack of penalties for non-compliance with shore power usage, regulations and policies such as the *Yangtze River Protection Law* have clarified detailed penalty provisions and legal bases for violations. Supervision and management measures for inland shore power usage have been continuously strengthened, with many regions conducting special inspections on shore power construction and usage while promoting pilot applications of shore power monitoring and service information systems.

For example, Shanghai, Jiangsu, and Anhui have issued anti-pollution regulations for ships, further clarifying and detailing the responsibilities and requirements for shore power construction and usage. In some areas, stricter oversight has been enforced by including non-compliant ships in credit blacklists. Under the rigorous supervision and management of shore power usage in various regions, ports along the Yangtze River have essentially achieved full compliance with shore power usage for eligible vessels.

In addition to promoting "maximum connectivity" and "full compliance" with shore power, the efficiency and quality of shore power services also impact the willingness of ship operators to use it. Currently, issues such as poor convenience in using shore power, low awareness among ship operators, and the unreasonable placement of some shore power facilities persist. In the future,

[80] Changjiang Navigation Authority of the Ministry of Transport (2024), Work Dynamics of Shore Power Supply for Ships in the Yangtze River Economic Belt, Issue 01 of 2024 (Total Issue 24).
[81] Changjiang Navigation Authority of the Ministry of Transport (2024), Work Dynamics of Shore Power Supply for Ships in the Yangtze River Economic Belt, Issue 01 of 2024 (Total Issue 24).

the promotion of shore power at inland ports will require further enhancement of "soft power."

Coastal ports, on the other hand, have long seen low utilization rates of shore power, creating a stark contrast with the progress in shore power construction. Overall, the primary factor currently limiting shore power usage at coastal ports is the insufficient installation rate of shore power reception facilities on docked ships. Addressing this issue will require efforts on multiple fronts, including regulatory enforcement, policy incentives, improvements in technical reliability, and strengthened collaboration among stakeholders.

In recent years, shipping companies have shown low enthusiasm for building and utilizing shore power reception facilities on their vessels. This is partly due to cost factors—using shore power at ports lacks a price advantage, and the investment costs for shore power facilities on ships are relatively high. Another reason lies in the variability of shore power supply, as the capacity of ports to provide shore power differs significantly across countries and regions, with issues such as insufficient shore power berths and non-standardized interfaces. These challenges have led to a generally low installation rate of shore power reception facilities on international ships, which remains the most direct obstacle to improving shore power utilization at China's coastal ports.

In recent years, relevant policies have begun driving an increase in shore power utilization at coastal ports. The *Implementation Plan for the Emission Control Area of Ship Air Pollutants* explicitly requires Chinese coastal vessels to be equipped with shore power reception facilities. Similarly, the *Marine Environmental Protection Law of the People's Republic of China* provides a legal basis for penalizing docked ships with the capability to use shore power but failing to do so as required.

Ports and shipping companies have also advanced shore power construction and usage through multi-party cooperation and strengthened industry self-regulation. For example, Shanghai Port and Shenzhen Port have taken active measures to promote the use of shore power by docked ships through signing port agreements, participating in green shipping corridors, and strengthening collaboration with shipping companies.

The government has played a key role in fostering ship-port cooperation for shore power usage. In August 2023, the Ministry of Transport released the *Action Plan for Demonstration and Promotion of Shore Power Use by International Route Container Ships and Cruise Ships (2023–2025)*, which aims to simultaneously enhance the installation rate of shore power facilities on both the port and ship sides.

(2) Clean Energy Transition for Port Service Vessels

Port service vessels primarily provide services for waterborne operations and transportation vessels and are one of the main sources of port emissions. Currently, the emission reduction measures implemented for port service vessels include the use of shore power while docked, lowering the sulfur content in fuel, installing exhaust after-treatment facilities, and adopting clean energy for newly built vessels. Among port service vessels, tugboats are the busiest, and these emission reduction measures are often focused on them.

Policies have played a key role in promoting cleaner fuels and the application of shore power technology. Currently, the sulfur content limit for port service vessels at inland ports in China has been reduced to 10 ppm, effectively cutting PM and SOx emissions. Over 20 major ports, including Ningbo-Zhoushan Port, Qingdao Port, and Suzhou Port, have achieved routine use of shore power for port service vessels. Port enterprises have actively carried out pilot demonstrations in the process of exploring cleaner solutions for tugboats, experimenting with technologies such as diesel-electric hybrid systems, LNG dual-fuel engines, and all-electric propulsion. Available data shows that more than 10 LNG dual-fuel, diesel-electric hybrid, and all-electric tugboats have been delivered or are under construction in China. Following the delivery of the "Yungang Electric Tug No. 1," an all-electric tugboat, Lianyungang Port has ordered a second all-electric tugboat, the "Yungang Electric Tug No. 2." All-electric tugboats offer the advantage of low operating and maintenance costs, and the practices of leading ports provide valuable experience for their wider adoption. Additionally, exhaust after-treatment technologies are also being applied at some ports. For example, Shenzhen Port has adopted selective catalytic reduction (SCR) technology on its tugboats to reduce NOx emissions.

Government departments and port enterprises play critical roles in advancing the clean energy transition of port tugboats. On one hand, government policies can raise the emission standards for newly built port tugboats, drive the phase-out, upgrading, and retrofitting of older tugboats, and introduce incentives for the research, development, procurement, and use of clean-energy tugboats. On the other hand, port enterprises should prioritize the potential for pollution reduction and carbon emissions mitigation in tugboats, strengthen technical collaboration, actively explore the application of clean-energy tugboats, and gradually eliminate high-emission tugboats. Considering future zero-emission goals, application scenarios for port tugboats, and existing experiences, all-electric tugboats will be one of the optimal choices in the future.

(3) Clean Energy Transition of Port Machinery

Port machinery primarily includes non-road mobile equipment used in port operations, such as ship loading and unloading equipment, horizontal transport equipment, yard equipment, and cargo handling vehicles. These machines are one of the main sources of port emissions. In addition to energy-saving technological upgrades, the main methods for reducing emissions from port machinery include low-carbon energy alternatives, primarily electrification (pure electric and fuel cell), and the upgrading of fuel-powered machinery emission standards.

For busy port machinery, replacing diesel engines with electric power not only reduces fuel costs but also significantly lowers the emission of air pollutants and greenhouse gases. In the process of electrifying port fuel-powered machinery, the electrification of rubber-tired gantry cranes (RTGs) began earliest and has shown notable results. To date, most major container terminals have completed the electrification of RTGs, and some ports have even carried out energy-saving modifications for the RTG transfer process, further reducing the reliance of RTGs on diesel fuel during operations.

With technological advancements and increasing pressure on ports to reduce emissions, the electrification of mobile machinery has gained attention, though its application is still in the early stages. Regarding new machinery, the electrification process for port equipment has begun to accelerate. In terms of equipment types, small-tonnage forklifts and stackers have seen relatively fast adoption. High-power all-electric machinery, such as reach stackers, loaders, and large-tonnage forklifts, has already been implemented at major ports such as Ningbo-Zhoushan Port, Guangzhou Port, Qingdao Port, Rizhao Port, Tianjin Port, Xiamen Port, and Beibu Gulf Port.

The electrification of mobile machinery is still at a low level, facing dual challenges. On one hand, the high purchase cost of electric mobile machinery and the underdeveloped technology for high-power machinery electrification are significant obstacles. On the other hand, electrification efforts mainly focus on new or upgraded machinery, and replacing existing fuel-powered machinery requires consideration of equipment usage cycles. The increase in penetration rates will still take time.

To promote the electrification of port machinery, policy guidance and incentives remain essential. Current government documents at various levels encourage the use of clean energy for new port machinery. Some local governments have set specific targets and provided financial subsidies and other incentive measures to accelerate the electrification process of port machinery.

Upgrading the emission standards for port fuel-powered machinery is also an important measure to reduce atmospheric pollutant emissions from these machines. This includes raising the emission limits for newly constructed non-road mobile machinery and implementing exhaust emission control for existing machinery. In December 2022, the National Stage IV (China IV) standards for non-road mobile machinery were officially implemented, further reducing emission limits. At the same time, emissions regulations for existing non-road mobile machinery have become stricter.

Local governments have strongly promoted the upgrading and elimination of fuel-powered machinery by setting clear control targets and designating areas where high-emission non-road mobile machinery is prohibited. Port enterprises have also adopted proactive emission control measures. For example, Beibu Gulf Port Co., Ltd. has designated high-emission non-road mobile machinery prohibition zones in the Tieshan Port and Shibuling operation areas within Beihai Port, with the company's restrictions being stricter than local requirements.

Although electrification is the future direction, fuel-powered machinery will still occupy a significant share of port machinery in the medium to short term. Therefore, energy substitution for port machinery and the energy-saving and emission-reduction efforts for traditional fuel-powered machinery must proceed simultaneously. It is recommended to focus on tightening emission standards, promoting retrofitting of existing machinery, and advancing the research and application of electric technology. Continued research on updating and upgrading non-road mobile machinery emission standards is necessary to reduce emissions from newly added machinery at the source. Additionally, promoting the upgrading or elimination of existing machinery will help reduce overall pollution emissions. Lastly, introducing incentive and guidance measures can encourage the research and development of high-power all-electric mobile machinery and the commercialization of these products, enhancing the willingness of ports to actively choose all-electric machinery.

(4) Clean Energy Transition of In-Port Transport Vehicles

In-port transport vehicles refer to the transportation equipment responsible for short-haul cargo movements within the terminal, including container trailers, tractors, dump trucks, and intelligent horizontal transport equipment used in automated terminals. In-port horizontal transport is not only a key segment of fuel consumption in ports but also a typical application scenario for new energy trucks, offering significant potential for the coordinated reduction of air pollutants and greenhouse gases. Currently, the clean energy transition path for in-port transport vehicles includes low-carbon energy alternatives and the upgrading of emission standards. Low-carbon energy alternatives primarily refer to new energy vehicles such as pure electric and fuel cell vehicles.

Currently, the use of low-carbon energy alternatives for in-port transport vehicles is beginning to take shape. Public data shows that 12 international container hub ports have deployed new energy vehicles to varying degrees[82]. With advancements in battery and charging/swapping technologies, the application of new energy vehicles in ports is accelerating. In terms of hydrogen energy application, ports such as Qingdao Port and Jiaxing Port are actively promoting the use of hydrogen fuel. As technology continues to develop, the benefits of new energy trucks in port applications are gradually becoming evident.

With the rapid development of technology, new energy vehicles hold greater economic and environmental potential in port short-haul scenarios. It is recommended that ports prioritize the purchase and updating of vehicles with new energy options. For existing fuel-powered vehicles, energy-saving and emission-reduction can be further achieved through optimized operational methods and strengthened regular maintenance. Additionally, the orderly phasing out and updating of high-emission, outdated fuel-powered vehicles should be promoted.

(5) Clean Energy Transition of Port Collection and Distribution Transport

Ports serve as the junctions for various modes of transportation, including waterways, highways, railways, and pipelines, and the emissions from port collection and distribution transport impact the port city and even surrounding areas. Among different transportation modes, railway and waterway transport are characterized by large capacity and low emission intensity, whereas road transport, mainly involving diesel trucks, not only causes congestion and safety issues in port cities but also generates significant air pollution. Therefore, promoting the shift of road-based collection and distribution transport to low-carbon modes like rail and water transport, and accelerating the decarbonization of collection and distribution, is a crucial aspect of traffic emission reduction in port cities.

In promoting the green and low-carbon development of collection and

[82] The international container hub seaports refer to 11 ports, including Shanghai Port, Dalian Port, Tianjin Port, Qingdao Port, Lianyungang Port, Ningbo-Zhoushan Port, Xiamen Port, Shenzhen Port, Guangzhou Port, Beibu Gulf Port, and Yangpu Port.

distribution transport, the Ministry of Transport has already set clear targets for the railway port share, the proportion of major port bulk cargo clean collection and distribution, and the annual growth rate of rail-water intermodal transport, along with key tasks and supporting measures. Local governments have also gradually introduced relevant policies, tailoring them to local conditions to build green and low-carbon collection and distribution systems. For example, Hebei Province has set bulk cargo clean collection and distribution targets that exceed national goals; Tangshan City has planned an urban-level battery swapping network to provide energy support for battery-swapping heavy trucks, aiding the decarbonization of road transport; and Shanghai has focused on addressing the gaps in port rail-water intermodal transport and further increasing the water-to-water transshipment ratio.

The formation of the port collection and distribution structure is closely related to factors such as infrastructure, transportation organization, geographical location, and economic hinterland, with different transportation modes having their applicable scenarios. For ports where road transport accounts for a high proportion, in addition to further exploring the potential for shifting cargo transport from road to rail and waterway collection and distribution, attention should also be given to the new energy alternatives for diesel trucks in road-based collection and distribution.

Some ports have already begun to take proactive measures in the clean energy transition of road transport, which are worth learning from. In addition to prohibiting "road transport-transported coal" at northern coal ports, some port cities have also implemented restrictions or incentive measures on the emission standards of diesel trucks entering and exiting the ports. In terms of the use of new energy vehicles, some cities have pilot programs to update the port collection and distribution fleet to new energy vehicles.

(6) Port Energy Transition

As a hub for both water and land transportation, ports not only have the potential to achieve low-carbon operations themselves but also play a key role as critical nodes in the logistics chain and energy transportation hubs, supporting the green transition of the logistics system and even surrounding regions. The port energy transition includes increasing the share of low-carbon energy, such as electricity, in the port's energy consumption structure, strengthening the application of green power, and exploring the supply of green fuels and energy.

i.Optimization of Energy Consumption Structure

The changes in the port energy consumption structure reflect the progress of various emission reduction measures. Currently, fossil fuel consumption still accounts for a large proportion of port energy use, and port emission reductions need to continue. Diesel remains a significant part of the total energy consumption at ports, primarily consumed by equipment such as port machinery powered by diesel engines, in-port transport vehicles, and port service vessels.

Different types of cargo handling processes have a considerable impact on the port's energy structure, with container terminals facing both potential opportunities and pressures for green transformation. Container terminals have high demands for in-terminal mobile machinery and horizontal transport vehicles, contributing significantly to fossil fuel consumption. For example, in a large container port, diesel and LNG consumed by in-port transport vehicles and handling machinery account for over 70% of the port's total diesel and LNG consumption, representing about 40% of the port’s total energy consumption. In contrast, bulk cargo ports primarily use electrically powered continuous conveyor systems.

To achieve long-term goals of near-zero or zero emissions, the transformation of the port energy consumption structure should shift from fossil fuels to low-carbon energy sources such as electricity or hydrogen, which have the potential for zero emissions over their entire life cycle. How to formulate a reasonable emission reduction technology pathway, align short-term emission reduction measures with long-term goals, and achieve port low-carbon energy substitution at a more reasonable cost are important issues that stakeholders in the port sector need to address.

ii. Application of Green Power in Ports

From a full life-cycle emission reduction perspective, as the port energy consumption structure shifts towards electric energy substitution, it is also important to actively promote the share of green energy within electricity and reduce the life-cycle greenhouse gas emissions of electricity. Ports can fully utilize their renewable energy potential by increasing the share of green power through technologies such as photovoltaic and wind power generation.

Photovoltaic and wind energy are applied in major ports, with distributed photovoltaic systems being the most widely used and wind power concentrated in areas with abundant wind resources. Some leading ports have made positive progress in the application of green power: Tianjin Port's wind and photovoltaic installed capacity and annual power generation capacity have reached a global leading level, accounting for about 20% of Tianjin Port's electricity consumption. Beibu Gulf Port has established a Zero Carbon Port Research and Development Center to explore and continuously carry out research on new energy generation projects, supporting the construction of a zero-carbon port. In addition, some ports have also reduced indirect emissions from electricity consumption by participating in green power trading.

21. What are the recommendations for emission reduction

(1) Accelerate the formulation of top-level design to guide carbon reduction efforts in the shipping industry.

In 2023, the International Maritime Organization revised its strategy for greenhouse gas emissions reduction from ships, marking an acceleration in the global green transformation of the shipping industry. In the same year, the European Union officially included the shipping industry in its carbon emissions trading system, indicating a significant increase in international pressure for carbon reduction. With China's last "14th Five-Year Plan" approaching before reaching carbon peak, and the increase in "road-to-water" and "rail-water intermodal" transport, the shipping industry will bear more cargo volume to assist other transportation sectors in achieving carbon peak and carbon neutrality. Therefore, the entire industry urgently needs top-level design to guide the implementation of "dual-carbon" efforts in shipping.

Set binding indicators such as carbon intensity for marine fuels and the electrification rate of ships, clearly defining specific goals and tasks for green and low-carbon development. Biomass fuels, green hydrogen, green methanol, green ammonia, and batteries are considered potential fuel options for low and zero-carbon ships. The establishment of binding indicators will help promote the production, processing, and use of low and zero-carbon fuels and power sources.

Release a roadmap and action plan for carbon peak and carbon neutrality in shipping, and improve the "1+N" policy framework. Since low and zero-carbon emission technologies for ships are still in the early stages, the introduction of the roadmap and action plan will promote reasonable division of labor within the industry, facilitating the joint development, demonstration, promotion, and application of low and zero-carbon emission technologies.

(2) Formulate stricter emission standards for inland waterway shipping.

Formulate stricter emission standards for inland waterway shipping and ensure effective enforcement by regulatory authorities. Through monitoring and tracking emission levels, impose penalties or restrictions on vessels that do not meet the standards, in order to encourage the shipping industry to reduce emissions.

(3) Increase financial and tax subsidies to unlock market potential.

At present, low and zero-carbon technologies have relatively poor economic viability. Therefore, to promote the large-scale adoption of low and zero-carbon technologies, it is necessary to introduce relevant financial and tax policies, similar to the support provided for new energy vehicles. This will help lower the purchase and usage costs, improve the investment returns for enterprises, and shorten the investment payback period.

(4) Create green shipping corridors to support technological innovation.

Green shipping corridors bring together stakeholders across the industry chain, including fuel producers, shipowners, cargo owners, and regulatory agencies, to jointly create an ecosystem for low and zero-carbon technologies. This is one of the pathways to demonstrate, promote, and apply emerging technologies. During the "14th Five-Year Plan" period, China could establish several inland green shipping corridors in economic regions such as the Yangtze River Basin and Pearl River Basin, promoting the demonstration, promotion, and application of low and zero-carbon technologies in inland vessels.

(5) Strengthen inter-industry cooperation to promote high-quality industrial development.

Electrification is one of the necessary pathways for ports to achieve carbon neutrality, but it will significantly increase the electricity load at ports. The shipping industry should work closely with the power industry to plan in advance and upgrade the power grid to meet the electricity demand of carbon-neutral ports.

Additionally, establishing industry alliances and partnerships is not only beneficial for forming industry consensus, such as standardizing skill requirements and talent training, but also promotes knowledge transfer to address industry development bottlenecks. Regularly holding industry exchange meetings and forums, publishing best practices and case studies, summarizing lessons learned, and standardizing commercial terms all contribute to helping the industry avoid unnecessary detours, thereby accelerating the development of low and zero-carbon technologies.

(6) Revise the knowledge system to improve the technical skills of industry professionals.

New energy vessels are an important vehicle platform for achieving carbon neutrality in the shipping industry and will replace traditional fossil fuel-powered vessels as the main mode of waterborne transportation in the future. Whether it is fully electric ships or methanol-fueled vessels, the knowledge structure required for these ships differs from conventional vessels. If industry professionals do not have the relevant knowledge and skills, the safe and stable operation of new energy vessels cannot be ensured, and carbon reduction in the shipping industry will be impossible.

Therefore, the shipping industry needs to update the existing knowledge system, strengthen the development of new energy vessel disciplines, and promote the transformation and upgrading of shipbuilding professions. Additionally, training programs for both new and existing employees should be implemented to enhance their professional skills, ensuring the smooth operation of new energy vessels.

(7) Increase industry transparency to promote healthy industry development.

For government-supported pilot and demonstration projects, it is recommended to promote increased transparency and public access to project data, such as cash flow, operating time, and operating mileage. Public and transparent data helps investors better assess technology, project, and market risks, supports the iteration of low and zero-carbon technologies, and benefits the entire industry by identifying key development pathways and challenges. This, in turn, allows for targeted support based on demand.

In addition, Chinese ports should compile and publicly disclose greenhouse gas and pollutant emission inventories, allowing the entire society to supervise their decarbonization process. Ships should create public databases for fuel consumption and emissions, which will not only prepare the necessary data for integrating shipping into China's carbon market but also help identify key emission sources on ships. This will support the development of targeted carbon reduction strategies at the national and local levels.

The implementation of these measures can help reduce emissions in China's shipping industry and drive its development towards a more sustainable and environmentally friendly direction. At the same time, to ensure the effective execution and continuous improvement of these measures, all stakeholders, including the government, industry associations, and shipping companies, need to work together collaboratively.

III Aviation Section

This section introduces the emission reduction targets set by various international levels for air transport and the corresponding policies introduced. It provides a comprehensive analysis of China's aviation demand, future forecasts, current emission levels, and expected changes. Additionally, it discusses key emission reduction pathways, such as the development and application of sustainable aviation fuels and electric aircraft. Based on this analysis, the section presents policy recommendations, including establishing an efficient coordination mechanism and improving innovation-driven supply-side incentive measures, to promote the green transformation and sustainable development of the aviation industry.

Keywords: Jet fuel carbon emissions, sustainable aviation fuels, electric aircraft, clean energy applications

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Chapter III Aviation Section

22. What emission reduction targets have been set by the international aviation industry?

Overall, aviation industries in developed countries like Europe and the U.S. have set net-zero carbon emission targets primarily for 2050 or earlier, as their growth is relatively slow. In contrast, developing countries like China, where the aviation sector is still in the stage of moderate to rapid growth, have set carbon neutrality targets for 2060 or later. This section introduces the specific emission reduction targets set by international organizations, countries, and airlines at three levels.

(1) International Civil Aviation Organization (ICAO) and International Air Transport Association (IATA)

The International Civil Aviation Organization (ICAO), a specialized agency under the United Nations, is responsible for regulating carbon emissions from international air transport, as these emissions have a transnational nature and are not suitable for management by any single sovereign country.

In September 2022, the 41st ICAO Assembly reviewed and adopted Resolution 21, which includes the comprehensive statement on the continuous policies and practices of ICAO regarding environmental protection. The "Long-term Aspirational Goal [83] " on climate change was approved, requiring the international aviation industry to achieve net-zero emissions by 2050. However, it is important to note that this goal is not legally binding for the aviation industries of individual countries, and the Civil Aviation Administration of China (CAAC) has reserved its position on this target.

In addition to the net-zero carbon emission target for 2050, the International Civil Aviation Organization (ICAO) also established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) [84] as early as the 39th Assembly in 2016. This created the world's first global carbon market mechanism for a single industry. The scheme requires participating countries to maintain the carbon emission levels of international flights from 2021 to 2035 at the same level as in 2020. Any excess emissions must be offset by airlines through the purchase of carbon reduction credits or the use of sustainable

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[83] ICAO, Long term global aspirational goal (LTAG) for international aviation. https://www.icao.int/environmental-protection/Pages/LTAG.aspx

[84] ICAO, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

aviation fuel. It is known that the Civil Aviation Administration of China (CAAC) has also reserved its position on the target setting and emission reduction responsibility distribution within the CORSIA framework.

In addition, at the third ICAO Conference on Aviation Alternative Fuels in November 2023, a target was adopted to promote energy transformation. The goal is for the carbon intensity of jet fuel used in international aviation activities to be reduced by 5% [85]compared to the current traditional jet fuel carbon intensity by 2030. [85]

The International Air Transport Association (IATA), an international NGO representing airlines headquartered in Geneva, Switzerland, announced the goal of achieving net-zero carbon emissions by 2050 at its 77th Annual General Meeting in 2021. However, it is important to note that this goal is not legally binding [86].

(2) Carbon Emission Reduction Targets for the Aviation Industry in Major Countries or Region

<u>United states</u>

In November 2021, the Federal Aviation Administration (FAA) released the *U.S. Aviation Climate Action Plan* [87], outlining the pathway for the U.S. aviation industry to achieve net-zero carbon emissions by 2050. The action plan primarily includes the following aspects: developing newer and more efficient aircraft and engine technologies, improving aircraft operational efficiency through national space systems, producing and using sustainable aviation fuel, exploring electrification or potential hydrogen solutions for short-haul aviation, optimizing airport operations, international cooperation and initiatives, and supporting research on climate change.

<u>European Union</u>

In July 2021, the European Commission passed a series of regulations, including

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[85] ICAO (2023), ICAO Global Framework for Sustainable Aviation Fuels, Low-Carbon Aviation Fuels, and Other Cleaner Aviation Energy Sources. https://www.icao.int/Meetings/CAAF3/Documents/Updates_Appendix%20to%20CAAF3.WP.009_Rev1_23Nov2300Y.ch.PDF

[86] IATA (2021), The "International Aviation Climate Declaration" acknowledges the net-zero carbon emission targets of airlines. https://www.iata.org/contentassets/8a8c7126d34b437991fe73dba29d74be/2021-11-12-01-cn.pdf

[87] FAA (2021), United States 2021 Aviation Climate Action Plan. https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_Climate_Action_Plan.pdf

the long-term goal[88] of achieving climate neutrality for the European aviation industry by 2050, and a mid-term target of reducing net emissions by 55%[89] by 2030. Subsequently, to achieve these goals, the EU introduced or revised several regulations related to carbon reduction in the aviation sector. These include the introduction of a mechanism for phasing out free carbon allowances for aviation in the EU Emissions Trading System (ETS), the release of the *Refuel EU Aviation* regulation, the revision of sustainable aviation fuel-related content, and the implementation of the EU Renewable Energy Directive III, among others.

Britain

In July 2022, the UK Department for Transport released the *Jet Zero Strategy: Delivering Net Zero Aviation by 2050*[90], which outlines the pathway for the UK aviation industry to achieve net-zero carbon emissions by 2050. The strategy includes improvements in system efficiency, the use of sustainable aviation fuels, zero-carbon aircraft (i.e. electric and hydrogen-powered planes), market mechanisms and carbon removal, influencing consumer behavior, and addressing non-CO_2 greenhouse gases, among other measures. Similar to the EU, the UK is also implementing or planning to implement policies such as carbon markets for the aviation industry and mandatory sustainable aviation fuel blending to achieve these goals.

Japan

In 2021, Japan passed the revised *Global Warming Countermeasures Promotion Act*[91], which clearly set the carbon neutrality target for 2050. The country plans to promote emission reductions in 14 key sectors, including electricity, new energy vehicles, hydrogen, shipping, aviation, and construction.

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[88] European Commission (2021), European Climate Law. https://climate.ec.europa.eu/eu-action/european-climate-law_en#:~:text=The%20European%20Climate%20Law%20writes,2030%2C%20compared%20to%201990%20levels.

[89] European Commission (2021), European Climate Law. https://climate.ec.europa.eu/eu-action/european-climate-law_en#:~:text=The%20European%20Climate%20Law%20writes,2030%2C%20compared%20to%201990%20levels.

[90] Department for Transport of the United Kingdo (2022), Jet Zero Strategy: Delivering Net Zero Aviation by2050. https://www.gov.uk/government/publications/jet-zero-strategy-delivering-net-zero-aviation-by-2050

[91] House of Councillors of Japan (2021), Act on Promotion of Global Warming Countermeasures. https://www.japaneselawtranslation.go.jp/en/laws/view/3796/en

Singapore

In February 2024, the Singaporean government released the *Singapore Sustainable Aviation Hub Blueprint*[92], which outlines how to achieve the net-zero carbon emission target by 2050 from the perspectives of airports, airlines, and air traffic management. The blueprint aims to make Singapore an international leader in sustainable aviation. A key focus for airlines is sustainable aviation fuel (SAF), and Singapore will take action in four key areas: setting national sustainable aviation fuel targets and charges, centralizing SAF procurement, and producing sustainable aviation fuel in the local area of Singapore and the surrounding region, among other initiatives.

China

Although the Chinese government and relevant departments have not yet set separate carbon peak or carbon neutrality targets for the civil aviation industry, the Civil Aviation Administration of China (CAAC) has outlined several goals in the *14th Five-Year Plan for Green Development in Civil Aviation*[93]. These goals include: for airlines, ensuring that by 2025, the cumulative fuel consumption per ton-kilometer does not exceed 0.293 kilograms, the cumulative CO_2 emissions per ton-kilometer do not exceed 0.886 kilograms, and the cumulative use of sustainable aviation fuel reaches 50,000 tons by 2025.

(3) Carbon Emission Reduction Targets of Major Airlines

The carbon emission reduction targets set by major airlines are mainly divided into three categories: first, the goal and timeline for achieving carbon neutrality; second, the targets related to the use of sustainable aviation fuel; and third, the targets under the Science-Based Targets Initiative (SBTi).

i.Carbon Neutrality Goal

In line with the carbon neutrality goals of their respective countries or regions, major airlines have set corresponding carbon neutrality targets and timetables. In Europe, British Airways, Lufthansa, Air France-KLM, Ryanair, EasyJet, and others have committed to achieving carbon neutrality by 2050. Some

[92] Civil Aviation Authority of Singapore (2024), Launch of Singapore Sustainable Air Hub Blueprint. https://www.caas.gov.sg/who-we-are/newsroom/Detail/launch-of-singapore-sustainable-air-hub-blueprint

[93] Civil Aviation Administration's Comprehensive Department (2022), Special Planning for Green Development of Civil Aviation During the 14th Five-Year Plan Period. https://www.gov.cn/zhengce/zhengceku/2022-01/28/5670938/files/c22e012963ce458782eb9cb7fea7e3e3.pdf

European airlines, such as Finnair, have even pledged to reach this goal earlier, by 2045. In North America, major airlines such as United Airlines, American Airlines, Delta Airlines, Southwest Airlines, Air Canada, and Aeromexico have committed to carbon neutrality by 2050. Even airlines like JetBlue Airways and Alaska Airlines in the United States have committed to achieving carbon neutrality by 2040. In Asia, airlines such as Japan's All Nippon Airways (ANA) and Japan Airlines, Singapore Airlines, South Korea's Korean Air, Taiwan's China Airlines and EVA Air, Hong Kong's Cathay Pacific, and Middle Eastern carriers like Qatar Airways and Etihad Airways have all committed to carbon neutrality by 2050. In Oceania, airlines such as Qantas, Air New Zealand, and Virgin Australia have also committed to carbon neutrality by 2050.

ii. Sustainable Aviation Fuel Related Goals

The aviation industry widely recognizes sustainable aviation fuel (SAF) as the most important means to achieve carbon neutrality, and thus many airlines have set medium-term goals for SAF usage. Airlines that aim to use 10% sustainable aviation fuel by 2030 include: International Airlines Group (IAG), KLM, United Airlines, Delta Airlines, SpiceJet, Aeromexico, Air Canada, Air France, Air New Zealand, Alaska Airlines, American Airlines, All Nippon Airways (ANA), British Airways, Cathay Pacific, Iberia Airlines, Japan Airlines, Royal Jordanian Airlines, Qatar Airways, and Virgin Australia. Some airlines have set even higher targets, such as DHL with a 30% SAF usage goal by 2030 and UPS with a 30% SAF usage goal by 2035. There are also airlines with more conservative targets, like Singapore Airlines, which aims to use 5% sustainable aviation fuel by 2030.

iii. Science Based Targets initiative (SBTi)

The Science Based Targets initiative (SBTi) is an organization that supports companies and financial institutions across various industries globally in setting science-based targets aligned with the climate goals of the Paris Agreement, specifically aiming to limit global warming to well below 2°C, or ideally to 1.5°C. These targets include Scope 1 emissions, Scope 2 emissions, and can also address Scope 3 emissions. The initiative is widely recognized internationally. In 1998, the World Resources Institute (WRI), the World Business Council for Sustainable Development (WBCSD), and other organizations jointly released the Greenhouse Gas Protocol, which introduced the concepts of Scope 1, Scope 2, and Scope 3 carbon emissions. Scope 1 emissions refer to greenhouse gas emissions directly generated by an organization’s activities, such as the burning of fossil fuels. For example, an airline’s fuel combustion during aircraft operation would fall under Scope 1. Scope 2 emissions refer to indirect greenhouse gas emissions from the consumption of purchased electricity, heating, or cooling, which are a result of an organization's operational activities. Scope 3 emissions refer to emissions from the entire value chain of an organization, including upstream and downstream activities outside the company's direct control, such as the emissions from manufacturing and transportation of the aviation fuel used by an airline. Currently, 29 airlines worldwide have submitted target-setting applications, with 14 of them having their targets approved. For further details, refer to Appendix 3.

23. What are the emission reduction policies of the aviation industry in major countries and regions?

To achieve emission reduction targets for the aviation industry, various countries have introduced relevant policies, primarily focusing on carbon markets and sustainable aviation fuel (SAF). Below is an introduction to these policies.

European union

The European Union is the most proactive region globally in promoting carbon emission reductions in the aviation industry, and therefore, the policies it has implemented are among the earliest. Below are three key policies related to the aviation industry.

- EU ETS (European Union Emissions Trading System): In 2005, to implement the responsibilities of Annex I countries under the 1997 Kyoto Protocol, the European Union launched the EU Emissions Trading System (EU ETS). It has four phases: 2005-2007, 2008-2012, 2013-2020, and 2021-2030. In 2008, the EU announced that from 2012, all flights departing from or arriving in the EU, regardless of the airline's registration country, would be included in the EU ETS. The total allocation of quotas for 2012 was determined based on 97% of the average emissions of all flights entering or leaving the EU during the period 2004-2006. For the 2013-2020 period, the total allocation was determined based on 95% of the average emissions of all EU flights during 2004-2006. A large portion of the total quota was allocated for free to airlines based on their transport turnover (ton-kilometers) in 2010 as a proportion of the total transport turnover for all flights included in the EU ETS that year. Subsequent updates stipulated that from 2021-2023, airlines would receive 2.2% fewer free quotas each year compared to the previous year. The latest updates state that in 2024, airlines will receive 75% of the 2023 quotas, 50% in 2025, and 0% starting in 2026.

However, due to opposition from countries such as China, the United States, Russia, and India to the EU's unilateral action of including international aviation emissions under its jurisdiction, the EU revised its legislation in 2012. The revised law only includes emissions from flights between two points within the EU (i.e., flights where both the departure and arrival airports are within the EU) in the EU ETS. This scope remained in place until 2026, after which the EU will assess whether to extend the inclusion of flights from 2027 and beyond.

- Refuel EU Aviation: This legislation is a key measure within the EU Green Deal, specifically targeting the aviation industry. It primarily addresses fuel suppliers within the EU, requiring them to blend a minimum proportion of sustainable aviation fuel (SAF) starting in 2025. There is also a specific requirement for synthetic fuels (mainly derived from electro-fuel technology) to meet a certain proportion. Additionally, airlines are obligated to report their fuel usage. The detailed proportion requirements are outlined in the table below. Moreover, there is a linked policy between Refuel EU Aviation and the EU ETS. Under the EU ETS, 20 million tons of free allowances have been reserved to reward airlines that exceed the required use of SAF or synthetic fuels under Refuel EU Aviation. This reward system primarily applies to flights between two points within the EU from 2024 to 2030.

Table 9 Minimum Proportion of Sustainable Aviation Fuel to Be Blended by Airlines Operating Within the EU

Year	Requirements
2025-2029	The minimum requirement for the proportion of sustainable aviation fuel that must be refueled annually is 2%.
2030-2034	The minimum requirement for the proportion of sustainable aviation fuel to be refueled annually is 6%, with the following details: from 2030 to 2031, the total proportion of synthetic aviation fuel should not be lower than 1.2%, and the annual proportion should not be lower than 0.7%; from 2032 to 2034, the total proportion of synthetic aviation fuel should not be lower than 2%, with an annual minimum of 1.2% for 2032-2033, and a minimum of 2% for 2034.
2035-2039	The minimum requirement for the proportion of sustainable aviation fuel to be refueled annually is 20%, with synthetic aviation fuel accounting for no less than 5%.
2040-2044	The minimum requirement for the proportion of sustainable aviation fuel to be refueled annually is 34%, with synthetic aviation fuel accounting for no less than 10%.
2045-2049	The minimum requirement for the proportion of sustainable aviation fuel to be refueled annually is 42%, with synthetic aviation fuel accounting for no less than 15%.
After 2050	The minimum requirement for the proportion of sustainable aviation fuel to be refueled annually is 60%, with synthetic aviation fuel accounting for no less than 35%.

- <u>Renewable Energy Directive (RED):</u> In 2009, the European Union introduced the Renewable Energy Directive, requiring energy producers and suppliers to continuously increase the proportion of renewable energy, including aviation fuel. In 2023, the EU approved the third phase of the RED, which includes the following key features specifically for aviation fuel: Firstly, by 2030, the consumption of renewable energy must reach 29%, or greenhouse gas emissions must be reduced by 14.5%; Secondly, considering that the green premium for sustainable aviation fuel (SAF) is much higher than in other industries, 1 ton of SAF that meets sustainability standards can be counted as 1.5 tons of usage for reporting purposes; Thirdly, many new requirements for raw materials and sustainability certifications have been added specifically for SAF.

<u>Britain</u>

In 2020, the United Kingdom officially "Brexited," and as a result, the UK withdrew from the EU Emissions Trading System (EU ETS). However, the UK quickly established its own carbon market, the UK ETS, which largely follows the same rules as the EU ETS. For the aviation industry, the UK ETS and EU ETS are similar, but flights from the UK to the EU are included in the UK ETS, while flights from the EU to the UK are included in the EU ETS.

In April 2024, the UK also officially announced its version of the "Refuel EU Aviation"[94] program, which is a mandatory requirement for fuel suppliers. The key points of this program are as follows:

- The first is the target. The main objective is to achieve 10% sustainable aviation fuel (SAF) usage by 2030 and 22% by 2040. The goal is to reduce emissions by 7% (2.7 million tons) by 2030 with SAF, and to achieve a 15% reduction in emissions (6.3 million tons) by 2040.

- The second is that annual targets will be set by 2030 to reach 10% and 22% by 2040. Starting in 2025, the target will be 2% usage (approximately 230,000 tons).

- The third is that there are specific regulations for different technological pathways of sustainable aviation fuel (SAF). For HEFA (Hydro processed Esters and Fatty Acids, using waste oils like used cooking oil as the main raw material), there will be no usage cap for 2025-2026. By 2030, its usage should not exceed 71%, and by 2040, it should not exceed 35%. For PtL (Power-to-Liquid), there will be minimum usage requirements starting in 2028: 0.2% in 2028, 0.5% in 2030, and 3.5% in 2040.

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[94]Department for Transport and The Rt Hon Louise Haigh MP (2024), Sustainable aviation fuel initiatives. https://www.gov.uk/government/speeches/sustainable-aviation-fuel-initiatives

- The fourth is the introduction of a "buy-out" mechanism. If suppliers are unable to meet the minimum usage requirements, they can fulfill their obligations by paying a fee. The buy-out price for HEFA is £4.70 per liter, and for PtL, the buy-out price is £5.00 per liter.

United States

At the federal level in the United States, there is no carbon market, and state-level carbon markets do not include the aviation industry. U.S. policies related to sustainable aviation fuel (SAF) mainly involve subsidies, tax incentives, and carbon credits.

In 2022, the Inflation Reduction Act was passed, offering subsidies ranging from $1 to $2 per gallon for domestically produced SAF that meets certain emissions reduction standards, with this program running from 2022 to 2027. Additionally, there are tax credits available for companies that blend SAF into conventional jet fuel.

At the state level, California's Low Carbon Fuel Standard (LCFS) mandates a certain proportion of renewable energy from energy suppliers. If a supplier falls short, they must buy credits from those who exceed the required amount. Illinois has also implemented tax incentives for the use of SAF in domestic flights.

Singapore

In February 2024, the Singaporean government released the "Singapore Sustainable Aviation Hub Blueprint," with sustainable aviation fuel (SAF) policies being a key focus. These policies primarily address four aspects:

- The first is setting national sustainable aviation fuel usage targets, aiming for 1% by 2026 and striving for 3-5% by 2030.

- The second is imposing a sustainable aviation fuel fee on passengers, excluding transit passengers. The fee varies based on flight distance and cabin class. For 2026, the fees are set at 3, 6, and 16 Singapore dollars for short, medium, and long-haul economy class passengers, respectively.

- The third aspect involves centralized procurement of sustainable aviation fuel. Airlines will charge passengers directly and submit the fees to the government. A designated government agency will centrally procure SAF and allocate it to airlines for use.

- The fourth aspect focuses on promoting the production of sustainable aviation fuel in Singapore and the surrounding region.

India

In 2023, the Indian government announced a policy to implement minimum blending requirements for sustainable aviation fuel (SAF) in international flights. The target is 1% by 2027, 2% by 2028, and 5% by 2030. This is a directive target, primarily aimed at promoting the domestic production of sustainable aviation fuel in India[95].

Japan

In 2022, the Japanese government announced a target of using 10% sustainable aviation fuel (SAF) by 2030, primarily aimed at domestic Japanese airlines and international flights. However, specific policies to implement this target have not yet been introduced.

Other countries

Now, more and more countries are beginning to consider setting sustainable aviation fuel usage targets or implementing policies for the use of sustainable aviation fuel, including China, Thailand, Malaysia, the United Arab Emirates, Canada, Brazil, and others.

[95] Bioenergy International(2023),India moves forward with bioCNG blending mandates. https://bioenergyinternational.com/india-moves-forward-with-biocng-blending-mandates/#:~:text=CBO%20will%20be%20voluntary%20till,CBO%20will%20be%205%20percent.

24. What is the status of China's air transport demand, future projections, and emissions?

(1) The level and trends of China's air passenger and cargo transport demand.

In 2023, the industry completed a total transport turnover of 118.83 billion ton-kilometers, a passenger turnover of 1,030.88 billion passenger-kilometers, and a cargo and mail turnover of 28.36 billion ton-kilometers, which recovered to 91.9%, 88.1%, and 107.8% of 2019 levels, respectively. In 2023, the industry completed passenger transport of 61.957 million passengers and cargo and mail transport of 7.354 million tons, which recovered to 93.9% and 97.6% of 2019 levels, respectively[96].

i.Top-down, based on the civil aviation development vision

The "Action Plan for Building a Strong Civil Aviation Nation in the New Era" is an important policy document outlining the medium- and long-term development goals for China's civil aviation industry. The document indicates that the period from 2021 to 2035 is the stage for building a strong civil aviation nation across multiple sectors, with the goal for 2035 being an average of one air trip per person. By reviewing the data on passenger traffic and transport turnover in China's civil aviation from 2000 to 2021, there is a linear correlation between the two. In cases where the number of air trips per person is approximately equal to the number of passengers transported, the per capita air travel frequency can serve as an important basis for forecasting civil aviation transport turnover.

The International Civil Aviation Organization (ICAO) in its Report on the Feasibility of a Long-Term Aspirational Goal (LTAG) for International Civil Aviation CO_2 Emission Reductions, Appendix M2: COVID-19 Forecast Scenario Development[97] made predictions on the annual growth rate of the aviation transport industry under three different scenarios. The predicted results are as follows.

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[96] According to the statistical summary of major production indicators for each month of 2023 b y the Civil Aviation Administration of China (CAAC).

[97] ICAO (2022), Report on the Feasibility of a Long-Term Aspirational Goal(LTAG)For International Civil Aviation CO_2 Emission Reductions Appendix M2 COVID-19 Forecast Scenario Development. https://www.icao.int/environmental-protection/LTAG/Documents/REPORT%20ON%20THE%20FEASIBILITY%20OF%20A%20LONG-TERM%20ASPIRATIONAL%20GOAL_en.pdf

Table 10 ICAO's Forecast of Future Industry Growth Rates

CAGR	International RGs				Domestic RGs			
	COVID-19: High	COVID-19: Mid	COVID-19: Low	LTF 2018	COVID-19: High	COVID-19: Mid	COVID-19: Low	LTF 2018
10 Years (Around 2030)	3.4%	2.6%	1.1%	4.2%	3.9%	3.0%	1.4%	4.3%
20 Years (Around 2040)	4.0%	3.5%	2.3%	4.2%	4.2%	3.6%	2.4%	4.2%
32 Years (Around 2050)	4.2%	3.8%	2.9%	4.3%	4.1%	3.7%	2.8%	4.0%

Note: The 2018 forecast refers to the pre-pandemic predictions made by the International Civil Aviation Organization (ICAO) regarding the average annual growth rate of the international and Chinese civil aviation industry.

Considering the trend of globalization shifting towards regionalization and China's integrated transport system under the "dual carbon" goals for low-carbon transportation options, it is expected that the annual growth rate of civil aviation transport turnover will largely align with international levels. Under all three scenarios, if there are no significant changes in the structure of air passenger and cargo transport or the route network, the transport turnover in 2035 (corresponding to approximately 1.3 billion passengers) is expected to double compared to 2019 (with passenger traffic of 660 million), thus achieving the goal of one air trip per person by 2035.

ii. Bottom-up, based on transport supply capacity

The realization of aviation transport turnover relies on aircraft. To meet the medium- and long-term development goals for civil aviation, forecasts for China's total population from the "National Population Development Plan (2016-2030)" (Guofa [2016] No. 87) and the "World Population Prospects 2022," combined with information on fleet structure, aircraft models, and age, are used to predict fleet renewal. This will provide support for overall development goals.

In terms of model updates, based on industry operations, aircraft manufacturer supply, and other factors, the principle of replacing older aircraft models with newer ones of the same type is applied, such as the A320Neo series replacing the A320 series, the B737-Max series replacing the B737-NG series, the A350 and A330Neo replacing the A330, and the B787 replacing the B747/B777. At the same time, the steady growth of the domestic aircraft operating ratio is also considered.

The forecast results indicate that by 2030, China's fleet size will be between

5,000 and 5,200 aircraft, with passenger transport reaching 900 million to 1 billion passengers.

Based on the development vision and fleet size, two results are formed: "top-down" and "bottom-up" predictions. The "bottom-up" approach forecasts that transport turnover will be higher than the "top-down" optimistic scenario before 2029, approximately the same as the "top-down" neutral scenario from 2030 to 2045, and close to the "top-down" pessimistic scenario after 2046.

The study found that there are certain differences between the results obtained from the "top-down" and "bottom-up" prediction models. Specifically, under the assumption that the medium- to long-term demand in the aviation transport market remains relatively stable (which usually corresponds to optimistic or neutral market development scenarios), the gap in transport turnover between the two prediction models is expected to be filled by the introduction of new aircraft models.

On the other hand, if significant changes in transport demand and methods are considered, the update of the existing fleet will be able to meet the expected growth in future transport demand. However, due to the slowdown in growth, the actual total transport turnover may be lower than the optimistic projections.

(2) The emission levels of China's aviation transport industry.

Aviation carbon emissions in civil aviation originate from flight activities that meet the demand for passenger and cargo air transport. With steady growth in industry transport turnover, fleet size, and airport numbers, the total carbon emissions from civil aviation are bound to increase. The majority of civil aviation carbon emissions come from the combustion of fossil fuels, with carbon dioxide emissions from aviation fuel combustion accounting for more than 95% of civil aviation carbon emissions.

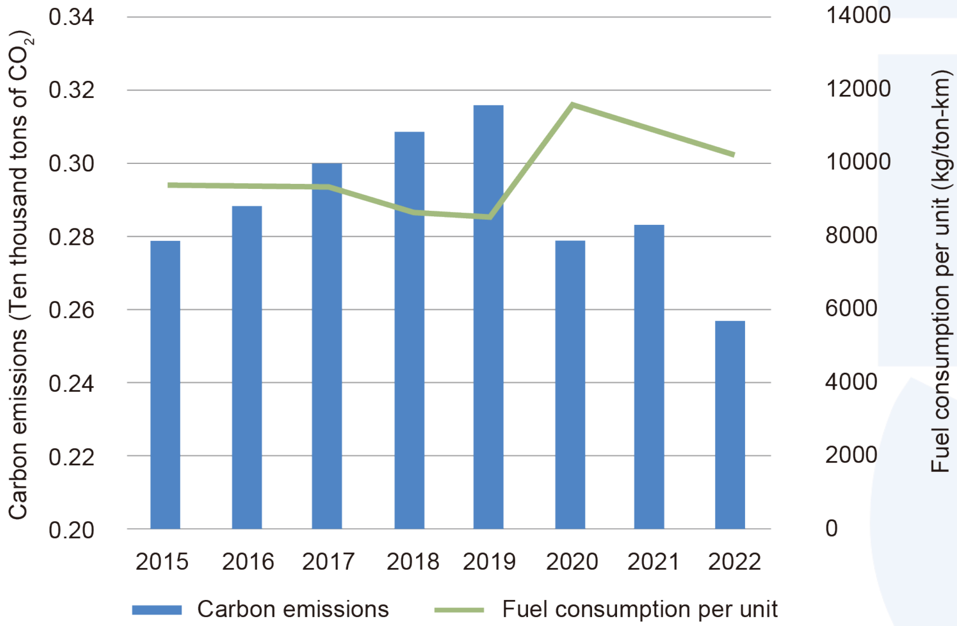
The calculation method for carbon emissions from aviation flight activities is as follows:

Energy consumption from flight activities × Carbon emission factor

Currently, the energy consumed during flight activities is aviation fuel (Jet A-1), with a carbon emission factor of 3.15 kg CO_2/kg. Therefore, at present, there is a strong positive correlation between aviation fuel consumption and transport turnover.

China's civil aviation carbon reduction measures mainly focus on improving energy efficiency and reducing carbon emissions per unit of output. Additionally, since the cost of aviation fuel and other energy sources accounts for a significant portion of operating costs, especially for airlines, industry has an inherent drive to engage in fuel and energy-saving initiatives. These include, but are not limited to, the active introduction of new fuel-efficient aircraft/engines, improving aircraft load factors, using energy-efficient ground equipment, and optimizing the management of flight activities.

In 2022, China's civil aviation fuel consumption per ton-kilometer was 0.302 kg, a decrease of 11.4% compared to 2005 (the base year for the industry's energy-saving and emission reduction targets). The average energy consumption per passenger and per passenger CO_2 emissions at airports increased by 26.1% and decreased by 21.6%, respectively, compared to the baseline (2013-2015 average).



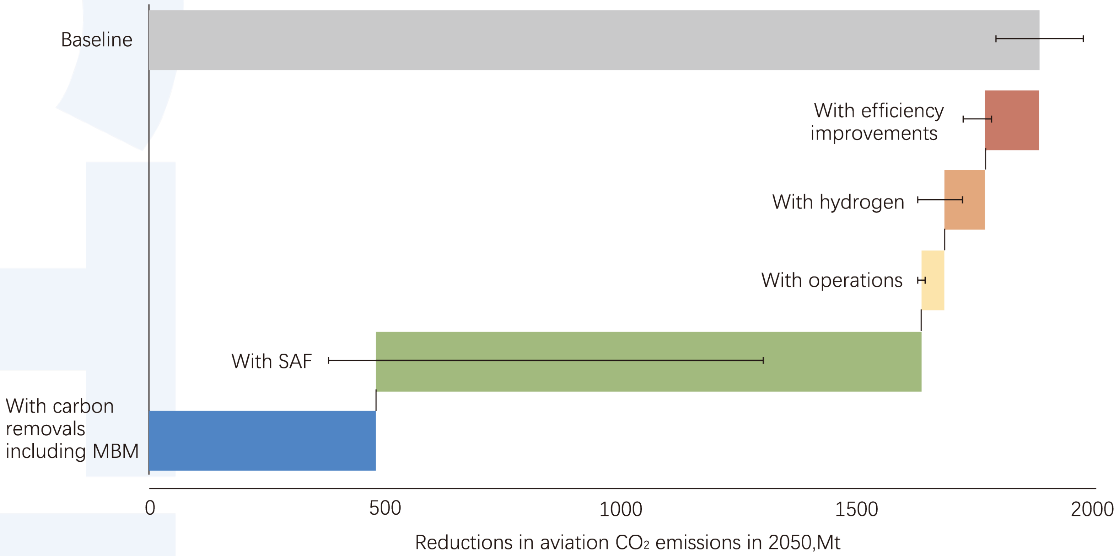
Source: Civil Aviation Administration of China, Statistical Bulletin on the Development of the Civil Aviation Industry in 2022

Figure 34 Fuel Consumption per Ton-Kilometer and Total Carbon Emissions of China's Civil Aviation Transport

25. As a key pathway for aviation emission reductions, how does sustainable aviation fuel play a role?

Compared to other modes of transportation such as road, rail, and waterways, decarbonizing civil aviation is extremely challenging. Accelerating the development of sustainable aviation fuel (SAF) has become the fundamental consensus for achieving a green transition in civil aviation before the middle of this century.

According to analyses by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA), the aviation industry's goal of carbon neutrality by 2050 will mainly be achieved through the following pathways: 1) fleet renewal with more fuel-efficient aircraft, 2) improvements in operational efficiency, 3) the use of electric and hydrogen-powered aircraft, 4) sustainable aviation fuel, and 5) carbon removal and carbon offset credits, among others. Among these, the largest emission reduction contribution comes from sustainable aviation fuel. According to IATA's 2050 zero-carbon roadmap research, the contribution of sustainable aviation fuel to emission reductions can reach over 60%, as shown in the diagram below[98]. The following will detail sustainable aviation fuel from three perspectives.



Source: Chart of the Week Getting to net-zero aviation – a bottom-up roadmap approach, International Air Transport Association (IATA) Sustainable Development and Economics.

Figure 35 IATA's 2050 Zero Carbon Roadmap

[98] International Air Transport Association (IATA) (2024), Executive Summary Net Zero Roadmaps. https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/executive-summary---net-zero-roadmaps.pdf

Sustainable aviation fuel (SAF) shares some similarities with traditional aviation fuel but also has key differences. The similarity lies in the fact that both provide power for aircraft operation through combustion. Therefore, the composition of SAF must be largely like that of traditional aviation fuel, and its physical and chemical properties, as well as combustion performance, must undergo certification to meet airworthiness standards, ensuring continued safety. As a result, the carbon emissions from SAF combustion are like those of traditional aviation fuel. The main difference is that the raw materials for SAF are primarily waste materials, residues, and other by-products, rather than crude oil. From a lifecycle perspective, SAF can reduce carbon emissions and generate little to no adverse economic, social, or environmental side effects, which is why it requires sustainable certification.

Earlier, it was mentioned that the combustion of sustainable aviation fuel (SAF) emits carbon dioxide just like traditional aviation fuel. So why is SAF considered a carbon-reducing fuel? The reasoning is as follows: raw materials for SAF, such as biomass or waste, absorb carbon dioxide during their growth process. When these materials are converted into aviation fuel, the combustion process simply releases the carbon dioxide that was previously absorbed, without adding extra carbon dioxide to the atmosphere. Moreover, this process occurs in a cyclical manner every year. In contrast, traditional fossil fuels release carbon that has been stored underground for millions of years, adding extra carbon dioxide to the atmosphere, which is a one-time event in human history.

There are three key factors involved in sustainable aviation fuel: airworthiness certification, sustainability certification, and raw materials.

(1) Airworthiness Certification of Sustainable Aviation Fuel

The airworthiness certification of sustainable aviation fuel (SAF) is mainly reflected in the physical and chemical properties, performance indicators, component compatibility, and engine testing, which all involve safety-related technical issues. The main airworthiness certification systems include the American Society for Testing and Materials (ASTM), with key documents such as ASTM D4054 "Standard Guide for the Evaluation of New Aviation Turbine Fuels and Additives" and D7566 "Standard for Aviation Turbine Fuel Containing Synthesized Hydrocarbons." In China, the relevant standard is CTSO-2C701 "Civil Aviation Jet Fuel Containing Synthesized Hydrocarbons." Among these, ASTM is the most widely recognized internationally. The International Civil Aviation

Organization (ICAO) website[99] has published sustainable aviation fuel production technologies and their respective maximum blending ratios that have passed ASTM certification. The details are as follows:

Table 11 Technical Pathways for Sustainable Aviation Fuel Production and Corresponding Maximum Blending Ratios

ASTM reference	Conversion process	Abbreviation	Possible Feedstocks	Maximum Blend Ratio
ASTM D7566 Annex A1	Fischer-Tropsch hydro processed synthesized paraffinic kerosene	FT	Coal, natural gas, biomass	50%
ASTM D7566 Annex A2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Vegetable oils, animal fats, used cooking oils	50%
ASTM D7566 Annex A3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%
ASTM D7566 Annex A4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Coal, natural gas, biomass	50%
ASTM D7566 Annex A5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Ethanol, isobutanol and isobutene from biomass	50%
ASTM D7566 Annex A6	Catalytic hydrothermolysis jet fuel	CHJ	Vegetable oils, animal fats, used cooking oils	50%
ASTM D7566 Annex A7	Synthesized paraffinic kerosene from hydrocarbon-hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%

[99] Data Source: ICAO official website, https://www.icao.int/environmental-protection/SAF/Pages/Conversion-processes.aspx.

ASTM D7566 Annex A8	Synthetic Paraffinic Kerosene with Aromatics	ATJ-SKA	C2-C5 alcohols from biomass	-
ASTM D1655 Annex A1	Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	-	Vegetable oils, animal fats, used cooking oils from biomass processed with petroleum	5%
ASTM D1655 Annex A1	Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	-	Fischer-Tropsch hydrocarbons co-processed with petroleum	5%
ASTM D1655 Annex A1	Co-Processing of HEFA	-	Hydroprocessed esters/fatty acids from biomass'	10%

Although 11 technology pathways have already been approved, this does not mean that they have all been successfully commercialized. Due to issues related to technological efficiency, costs, and the availability of compatible raw materials, the technology pathways with significant potential for large-scale commercialization are mainly: FT-SKA (Gasification and Hydrogenation), HEFA (Hydroprocessed Esters and Fatty Acids), and ATJ-SPK (Alcohol to Jet Synthetic Paraffinic Kerosene), among others. Additionally, several other sustainable aviation fuel technology pathways are currently in the process of applying for ASTM approval, primarily including:

Table 12 Table of Technical Pathways Under Application for ASTM Approval

Conversion Process Under Evaluation	Abbreviation	Lead Developers
Synthesized aromatic kerosene	SAK	Virent
Integrated hydropyrolysis and hydroconversion	IH2	(Shell)
Single Reactor HEFA (Drop-in Liquid Sustainable Aviation and Automotive Fuel)	DILSAAF	Indian CSIR-IIP
Pyrolysis of non-recyclable plastics	ReOIL	(OMV)
Co-processing of pyrolysis oil from used tires	TPO	Phillips 66
Methanol to jet	MTJ	(ExxonMobil)
Increase in fatty acid/ester co-processing from 5% to 30%		
HEFA with higher cycloparaffins		Revo
Biomass pyrolysis		Alder
Biomass/Waste pyrolysis		Green Lizard
Cycloalkanes from Ethanol		Vertimass

(2) Sustainable Certification of Sustainable Aviation Fuel (SAF)

Through third-party assessments conducted across the entire lifecycle, from raw material cultivation, harvesting, storage, processing, and conversion to fuel transportation and blending, based on certain standards, we ensure high emission reduction effects while having positive impacts on the economy, society, and the environment. The main environmental indicators include carbon storage, land productivity, waste, energy efficiency, air impact, soil impact, water resource impact, greenhouse gases, biodiversity, etc. The main social indicators include local food security, rural social development, continuous improvement, water rights, land rights and land use, labor rights, etc. The main economic indicators include job opportunities, economic sustainability, income growth, prices, and food supply.

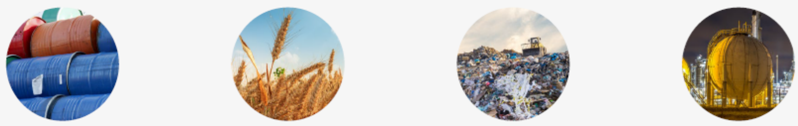
Internationally, relevant certification standards primarily include RSB (Roundtable on Sustainable Biofuels), ISCC (International Sustainability and Carbon Certification), EU RED (European Union Renewable Energy Directive), and US RFS (U.S. Renewable Fuel Standard). Only after certification according to these standards can we know the emission reduction coefficient of that batch of SAF.

(3) Raw Materials for Sustainable Aviation Fuel (SAF)

The commercialization of SAF essentially involves different technological pathways and types of raw materials being matched and competing with each other. The main types of raw materials include the following:

- Waste and residues: Waste oils and fats like used cooking oil, agricultural and forestry waste like straw, and municipal solid waste.
- Energy crops: Some energy crops can also be used as food for humans, such as corn and sugarcane, while others are non-food crops and are only used for industrial purposes, such as miscanthus and castor beans.
- Green electricity and captured carbon dioxide: This type of raw material can theoretically be supplied indefinitely.

In November 2020, the World Economic Forum's "Clean Skies for Tomorrow" initiative released a sustainable aviation fuel analysis report. The report analyzed the future production capacity of sustainable aviation fuel from two dimensions: technological pathways and raw materials.



	HEFA	Alcohol-to-jet[i]	Gasification/FT	Power-to-liquid
Opportunity description	Safe, proven, and scalable technology		Potential in the mid-term, however significant techno-economical uncertainty	Proof of concept 2025+, primarily where cheap high-volume electricity is available
Technology maturity	Mature		Commercial pilot	In development
Feedstock	Waste and residue lipids, purposely grown oil energy plants[ii] Transportable and with existing supply chains Potential to cover 5%-10% of total jet fuel demand		Agricultural and forestry residues, municipal solid waste[iv], purposely grown cellulosic energy crops[v] High availability of cheap feedstock, but fragmented collection	CO_2 and green electricity Unlimited potential via direct air capture Point source capture as bridging technology
% LCA GHG reduction vs. fossil jet	73%–84%[iii]		85%-94%[vi]	99%[vii]

i. Ethanol route; ii. Oilseed bearing trees on low-ILUC degraded land or as rotational oil cover crops; iii. Excluding all edible oil crops; iv. Mainly used for gas./FT; v. As rotational cover crops; vi. Excluding all edible sugars; vii. Up to 100% with a fully decarbonized supply chain

Source: CORSIA; RED II; De Jong et al. 2017; GLOBIUM 2015; ICCT 2017; ICCT 2019; E4tech 2020; Hayward et al. 2014; ENERGINET renewables catalogue; Van Dyk et al., 2019; NRL 2010; Umweltbundesamt 2016

Image Source: World Economic Forum, McKinsey & Company, Clean Skies for Tomorrow Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation

Figure 36 Maturity of Feedstocks and Technologies for Various Sustainable

Aviation Fuel Pathways

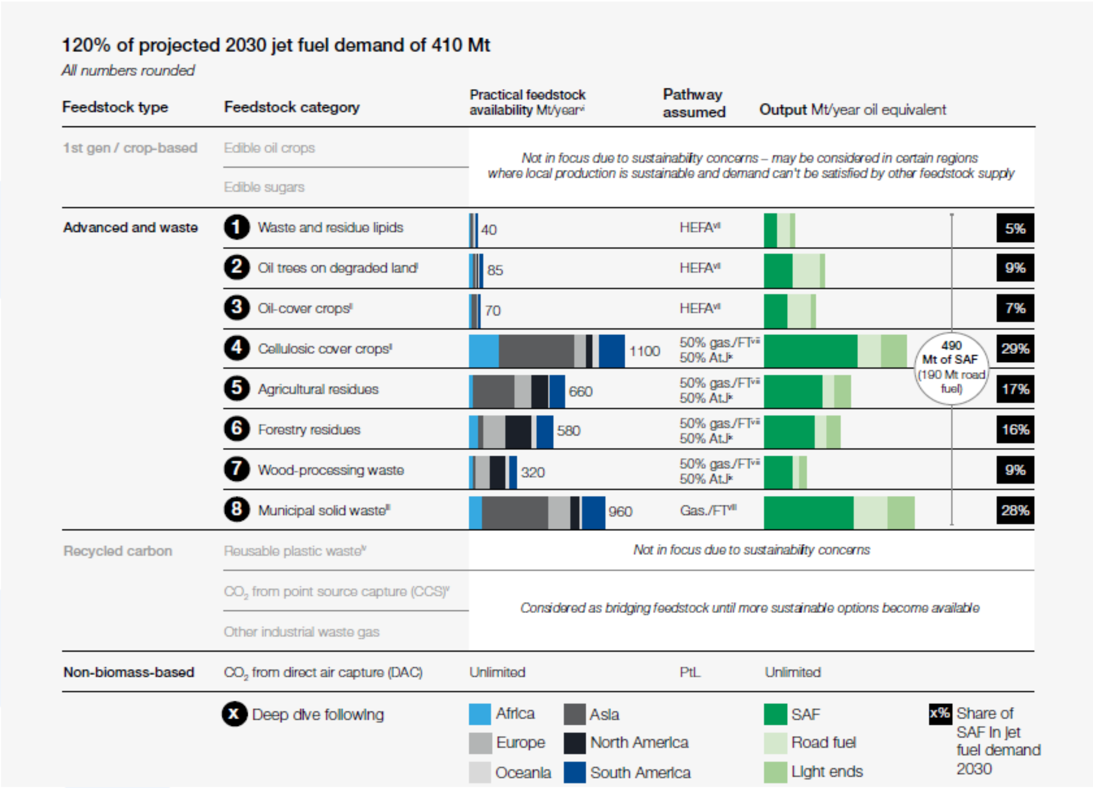


Image Source: World Economic Forum, McKinsey & Company, Clean Skies for Tomorrow Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation

Figure 37 Analysis of Global Supply Potential for Sustainable Aviation Fuel Feedstocks

According to this analysis, if the policies are appropriate and all stakeholders cooperate effectively, raw materials globally can meet the demand for producing sustainable aviation fuel by 2030 to completely replace traditional aviation fuel.

(4) Recommendations for the Promotion of Sustainable Aviation Fuel

i.Establish an Efficient Coordination Mechanism

Improving the economic viability of SAF (Sustainable Aviation Fuel) application is one of the system-wide goals requiring collaboration across the entire industry chain. Key factors such as raw material supply, refining, and technological innovation play a significant role, while the independent driving force from industry authorities is limited. Therefore, it is recommended to establish an SAF coordination mechanism to oversee and coordinate the development of the entire industry chain, ensuring efficient operation at each stage and maximizing the emission reduction potential of SAF.

ii. Improve Innovation-Driven Supply-Side Incentive Measures

Drawing on China's existing experience with biofuels, a combination of policy support and commercial incentives should be adopted to expand the SAF market. This can be achieved by establishing an industry development alliance with multi-party participation, leveraging the collaborative advantages of the alliance, and making full use of fiscal and tax tools to steadily expand scale effects and continuously reduce production costs. Additionally, consideration should be given to providing targeted subsidies or tax incentives to upstream companies involved in SAF production (such as raw material suppliers) to encourage them to improve the stability and production capacity of the supply chain. At the same time, public-private partnerships should be encouraged to promote innovation in SAF production technologies and facilitate market adoption.

iii. Promote Market-Based Mechanisms

Introduce market-based incentive mechanisms, such as carbon trading systems and green financial tools, to encourage airlines to prioritize the procurement and use of SAF. At the same time, by setting SAF usage quotas or targets, airlines can gradually increase their use of SAF, ensuring that emission reduction goals are met while fostering the healthy development of the market.

iv. International Cooperation

Reducing emissions in the aviation industry requires global collaboration. It is important to actively participate in the work of international organizations such as the International Civil Aviation Organization (ICAO) to promote global uniformity in aviation carbon emission standards and reduction targets, ensuring that carbon emissions from international flights are effectively controlled. Additionally, strengthening cooperation with other countries and regions is essential to share advanced technologies and experiences, collectively addressing the challenges of aviation carbon emissions. We should also actively advocate for and promote policies and measures for the green and low-carbon development of the global aviation industry, working together to tackle climate change.

26. What is the development outlook for emerging technologies – electric aircraft?

The global aviation industry is working towards achieving net-zero emissions by 2050. To achieve this, multiple measures are being implemented both within and outside the aviation industry, including improving aircraft efficiency, adopting sustainable aviation fuel (SAF), and developing electric and hydrogen-powered aircraft.

Electric aviation is referred to as the third revolution in aviation technology and represents an innovative direction for aviation technology and industry. By adopting distributed electric propulsion (DEP) designs, aircraft can significantly reduce their reliance on fossil fuels, thus lowering carbon emissions. Lightweight design and advanced battery technology further enhance energy efficiency and range. Additionally, electric designs can be effectively combined with renewable energy sources, such as solar and hydrogen power, to reduce environmental pollution. However, progress in electrifying large aircraft, such as commercial passenger planes, remains slow due to the current maturity level of electric technology, and no full-size prototypes are yet available. In the general aviation sector, electric vertical take-off and landing aircraft (eVTOL) for medium- and short-range flights have experienced explosive growth and have become a key focus for developing the low-altitude economy.

(1) Main operating scenarios of electric vertical takeoff and landing (eVTOL) aircraft.

Electric Vertical Takeoff and Landing (eVTOL) aircraft, also known as flying cars, are aircraft that use electricity as their power source and have vertical takeoff and landing capabilities. Based on their types and application scenarios, they can be divided into three main categories: surveillance aircraft, cargo aircraft, and passenger aircraft.

Surveillance aircraft	Amateur	Urban patrol and surveillance	Learning, training, and data collection
	Media and entertainment	Emergency communication network	Security and people search
	Inspection of agriculture, forestry, livestock and fishery	Remote sensing mapping	Military defense
Cargo aircraft	Agriculture cultivation and fertilization	Cargo transportation	
	Air traffic control and management	Expanded delivery range to remote areas	
	Express timed delivery	Emergency transportation(drugs and organs)	
Passenger aircraft	Private aircraft	Airbus	
	Rental	Emergency rescue	
	Air taxi		

Source: Porsche Management Consulting, 2023 Outlook Report on China's Vertical Mobility Market

Figure 38 Classification of eVTOL Application Scenarios

In China, urban low-altitude transportation is a highly regulated industry. The Civil Aviation Administration of China (CAAC), as the national authority responsible for civil aviation air traffic management, oversees the unified management of both domestic and foreign civil aircraft and airspace division. According to the CAAC's "National Airspace Classification Method," airspace is divided into seven categories—A, B, C, D, E, G, and W—based on factors such as aircraft flight rules, performance requirements, airspace environment, and air traffic control services.

The document states that air traffic control will no longer be applied to the newly classified G and W airspaces, laying the policy foundation for the pilot operations and commercialization of flying cars in uncontrolled airspace. The cruising altitude for civil aircraft typically starts at over 3,000 meters, and they are managed and coordinated by air traffic control centers. Flying cars, depending on their design, mainly operate in E-class (3,000-300 meters) and G-class (300-120 meters) airspace, with ranges typically between 50-300 kilometers.

Manned vertical takeoff and landing aircraft and cargo logistics vertical takeoff and landing aircraft fall under the category of low-altitude general aviation, managed by the Unmanned Traffic Management Center. Manned eVTOL aircraft generally operate below 300 meters in medium-to-low altitude airspace, while cargo logistics eVTOL aircraft typically fly at altitudes no higher than 120 meters.

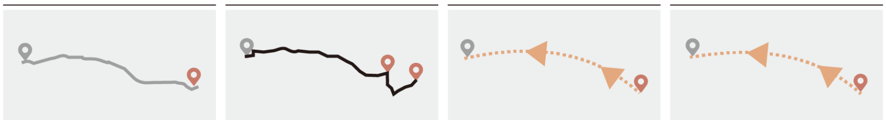
Based on statistical analysis of historical travel data, civil aviation aircraft mainly cover long-distance travel needs of over 800 kilometers, high-speed rail primarily serves medium-to-long-distance travel needs of about 400-1,000 kilometers, cars mainly cater to short-distance travel needs of about 5-200 kilometers, while helicopters and eVTOLs mainly cover medium-to-short-distance travel needs of about 50-400 kilometers.

As the population of large cities continues to grow worldwide, urban ground transportation infrastructure is becoming increasingly saturated. Subways and light rail, due to their limited geographic coverage and huge investment costs, are unable to meet the growing commuting demands. The existing urban transportation models are reaching their limits, severely affecting urban operational efficiency and the comfort and convenience of urban residents, while also placing an increasing burden on the ecological environment. For urban transportation needs within a 20–50-kilometer range, eVTOLs, benefiting from shorter travel times, will substitute traditional modes of transport such as cars and subways. For intercity transportation needs of around 100-300 kilometers, eVTOLs will primarily compete with intercity buses, cars, and high-speed rail.

(2) The energy-saving and emission reduction advantages of electric vertical takeoff and landing (eVTOL) aircraft.

Compared to traditional modes of transportation such as cars and high-speed trains, eVTOLs offer advantages in specific distance ranges, including high efficiency, convenience, low noise, low carbon emissions, and comfort and privacy. Compared to traditional aircraft such as helicopters, eVTOLs have clear cost and environmental benefits. Additionally, due to their lightweight, modular, and distributed electric drive architecture, eVTOLs have a competitive advantage in terms of overall operational and maintenance costs and complexity compared to helicopters. With the mass production of eVTOL products, it is expected that one-way ticket prices will continue to decrease and eventually align with those of luxury cars. Compared to helicopters, eVTOLs also offer core advantages in price, time, comfort, convenience, low noise, and zero carbon emissions. Given the limitations of infrastructure, such as the relatively limited number of helicopter helipads, as vertical takeoff and landing sites gradually expand and form networks, eVTOLs are expected to have even more significant advantages in terms of time efficiency and price.

	Luxury car travel	Business class travel on high-speed trains	Helicopter travel	eVTOL
Actual route schematic				
Total distance (km)	88	16 84 100	81	81
Time (min)	90	30 30 30 90	10 30 10 50	10 22 10 42
Average speed (km/h)	59	66	97	116
Price (RMB)	~ 900	~ 286 (Car-160RMB, High-speed train-126RMB)	~ 30,000	~ 1,500
Direct carbon emissions (km/g)	~ 6181	1,100	~ 41,187	0



eVTOL has significant advantages in terms of total travel time, carbon emissions, privacy, and comfort level.

Source: Porsche Management Consulting, 2023 Outlook Report on China's Vertical Mobility Market

Figure 39 Analysis of Energy-Saving and Emission-Reduction Advantages of Electric Vertical Take-off and Landing Aircraft

Thanks to its fully electric power system, eVTOLs produce almost no direct carbon emissions during operation. According to a report by the International Energy Agency (IEA), global aviation accounts for about 2% of total CO_2 emissions, with a growing trend. The use of eVTOLs can significantly reduce this number, especially when the electricity comes from renewable sources such as wind and solar energy, making their carbon footprint during operation close to zero. Moreover, electric motors generally have higher conversion efficiency than traditional fuel engines. NASA's research shows that electric aircraft consume about 50% less energy than traditional aircraft of the same size[100]. This data also applies to eVTOLs, as the electric propulsion system can more efficiently convert electrical energy into flight power, offering significant energy efficiency advantages over traditional helicopters or other fuel-powered VTOLs.

The noise produced by eVTOL electric engines is much lower than that of traditional fuel engines. According to the European Union Aviation Safety Agency (EASA), eVTOLs can have noise levels as low as one-tenth of conventional aircraft. This is crucial for improving noise pollution in urban air transport, contributing to better quality of life in urban environments. For example, the Lilium Jet electric vertical takeoff and landing aircraft, which uses a fully electric propulsion system, aims for zero direct emissions. Its energy consumption is only one-tenth of that of a helicopter, reducing both operational costs and environmental impact.

(3) Domestic and international policies and regulations for electric vertical takeoff and landing (eVTOL) aircraft.

<u>International Policies</u>

In recent years, developed countries such as the US, Europe, Japan, and South Korea have accelerated the development of rules and standards in the low-altitude economy and eVTOL sectors, promoting the growth of the eVTOL industry from both the supply side (airworthiness certification, aircraft development, operations, and supervision) and the demand side (cargo and passenger transport).

The European Union Aviation Safety Agency (EASA) has taken a pioneering role in the regulation of eVTOLs, planning to establish a completely new regulatory framework from scratch. In July 2019, EASA released the Special Condition for small-category VTOL aircraft. On December 9, 2019, Volocopter received Design Organization Approval (DOA), becoming the first eVTOL startup to obtain approval for a VTOL aircraft.

On March 13, 2020, EASA took the lead in publishing the world’s first draft rules for urban air mobility (UAM), titled the "High-level regulatory framework for the

[100] Nateri Madavan.Nasa investments in electric propulsion technologies for large commercial aircraft. Nasa Ames Research Center, Moffett Field, California, Electric and Hybrid Aerospace Technology Symposium, 2016.

U-space."[101] According to EASA, under this regulatory framework, commercial drone services can coexist with other activities in urban environments. The aim is to ensure safe operations while laying the commercial foundation for a competitive urban service market, and establishing environmental protection, safety, and privacy standards that are acceptable to the public.

On May 26, 2020, EASA published the proposed means of compliance with the special condition VTOL (MOCs) for eVTOL airworthiness certification. While the previous airworthiness certification clauses established safety and design objectives for eVTOL aircraft, they did not outline how aircraft developers could demonstrate compliance with these set goals. This proposed compliance review method provides detailed guidance on how to prove the safety of eVTOL aircraft and systems.

The Federal Aviation Administration (FAA) in the United States tends to develop policies for electric vertical takeoff and landing (eVTOL) aircraft based on existing airworthiness regulations, incorporating specific conditions to address airworthiness issues. This means eVTOL projects are evaluated according to Amendment 23-64 of the Part 23 airworthiness standards (Part 23 - Airworthiness Standards: Normal Category Airplanes), which provides FAA-accepted means of compliance for Part 23 airplanes. In March 2023, the White House Office of Science and Technology Policy (OSTP) released the "National Aerospace Technology Priorities," which proposed prioritizing the development of eVTOLs and other Advanced Air Mobility (AAM) vehicles.

In July 2020, Japan's Cabinet released the "Growth Strategy Follow-up Plan," beginning to formulate a low-altitude economy strategy at the national level. The plan set timelines for the development of safety standards, air logistics services, and eVTOL trial operations. By 2022, aircraft-based beyond-visual-line-of-sight (BVLOS) logistics services were to be implemented in specific empty cities; and in 2023, the "flying car" business was scheduled to begin trials.

In January 2023, the Korea Civil Aviation Authority (KOCA) and the Federal Aviation Administration (FAA) reached a cooperation agreement on the development and operation of future advanced air mobility aircraft, working together to promote the safety oversight of advanced air traffic projects.

<u>Domesticate Policies</u>

As an important component of the low-altitude economy, the development of

[101] The European Aviation Safety Agency (2020), Opinion 01/2020 High-level regulatory framework for the U-space. https://www.easa.europa.eu/en/document-library/opinions/opinion-012020

the eVTOL industry is expected to exceed expectations with policy support. Since 2021, eVTOL has entered a fast development track. China has introduced a series of policy documents to actively promote the development of the low-altitude economy, represented by eVTOL.

In 2022, the Ministry of Transport and the Ministry of Science and Technology jointly issued the "Outline of the Medium- and Long-Term Development Plan for Technological Innovation in the Transportation Sector (2021-2035)." It clearly proposed the deployment of flying car research and development, aiming to break through technologies such as the integration of aircraft and automobiles and the seamless switching between flying and ground driving.

On October 10, 2023, the Ministry of Industry and Information Technology and other four departments issued the "Outline for the Development of the Green Aviation Manufacturing Industry (2023-2035)." The document emphasizes accelerating the application of innovative products such as eVTOL (flying cars) and aims to form the supply capacity, operational support capacity, and industrial development capability for electric aircraft, guided by typical scenarios, to create a new economic growth driver. By 2025, the goal is to demonstrate the use of sustainable aviation fuel in domestic civil aircraft, commercial application of electric general aviation aircraft, pilot operations for electric vertical takeoff and landing aircraft (eVTOL), and feasibility validation of key hydrogen-powered aircraft technologies. By 2035, a complete, advanced, and safe green aviation manufacturing system will be established, with new energy aircraft becoming the mainstream of development.

On March 27, 2024, the Civil Aviation Administration of China (CAAC) and four other departments issued the "General Aviation Equipment Innovation and Application Implementation Plan (2024-2030)." The plan proposes that by 2030, a new development model for the general aviation industry characterized by high-end, intelligent, and green features will be basically established. This will support and ensure the safe and efficient operation of passenger networks for "short-distance transport + electric vertical takeoff and landing" aircraft, "trunk-feeder-end" drone delivery networks, and low-altitude production operation networks for agricultural and industrial tasks. General aviation equipment will be fully integrated into all sectors of people's production and daily life, becoming a strong driving force for low-altitude economic growth, forming a trillion-dollar market. The plan encourages the research and development of flying car technologies, product validation, and exploration of commercial application scenarios. It also aims to continually improve product competitiveness and market adaptability to meet the demands of agricultural, forestry, and industrial applications.

At the local level, cities like Shanghai, Shenzhen, and Hefei have introduced a series of policies and measures to promote the electrification of aircraft and the development of the low-altitude economy industry.

(4) Suggestions for Promoting Electric Aircraft

Electric aircraft have significant emission reduction potential. Efforts should be increased to support the research and development of these technologies by providing funding and policy incentives, promoting their early commercialization, and actively supporting the construction of related infrastructure. Efforts should also be made to develop international standards and certification systems for electric aircraft, promote technological exchange and cooperation, and accelerate the global application and adoption of these technologies.

i.Strengthen the Demand-Driven Traction of the Flying Car Industry

By extensively integrating resources from the industrial chain, innovation chain, and supply chain, and deepening industry-university-research cooperation, we will focus on industry demand as the driving force. We will organize and carry out joint technological breakthroughs, promote the conversion and application of basic research outcomes, and empower the development of the flying car industry. We will drive technological innovation in flying cars, lead high-quality supply, and create new demand, using the traction of expanded scale and structural upgrades to stimulate high-quality supply.

ii. Breakthrough Core Technologies for the Development of Flying Cars

To break through the core technologies for the development of flying cars, special projects will be set up to integrate advantageous resources from the fields of aviation, automobiles, and transportation, creating a cross-disciplinary innovation system. We will conduct joint research on major issues and collaboratively overcome key foundational technologies such as new energy power, land-air amphibious platforms, and 3D intelligent transportation. We will accelerate the application of technological achievements in real-world scenarios and drive continuous technological iteration, promoting the sustained development of the flying car industry.

iii. Innovate the Industrial Model for the Development of Flying Cars

To innovate the industrial model for the development of flying cars, a number of future industry innovation development pilot zones for flying cars will be established. These pilot zones will be supported to lead the research on the future flying car industry and layout the future industry. The zones will be encouraged to establish cooperative mechanisms with high-level research institutes and leading technology enterprises to jointly advance the development of flight technologies and scene-based supply. By conducting pilot demonstrations in fields such as low-altitude logistics, high-rise firefighting, and emergency rescue, we will promote product iteration and the construction of supporting systems, creating future industry clusters for the development of flying cars.

iv. Strengthen the Regulatory Framework for Flying Cars

To promote the development of the flying car industry, it is essential to strengthen the relevant regulatory framework. Targeted laws and regulations will be formulated to address the unique attributes and operational characteristics of flying cars, including airworthiness certification policies, product registration and registration policies, and operational management policies. We will ensure the safe operation of flying cars in accordance with the law, foster the healthy development of the industry, and create a favorable legal environment for the flying car industry.

IV Section of Structural Adjustment of Transportation (Passenger Transport)

This chapter focuses on passenger transport structural adjustments, primarily exploring the current state, development, and future prospects of China's high-speed rail (HSR) and civil aviation passenger transport sectors. Over the past decade, both HSR and civil aviation have achieved remarkable growth. Under the strategic framework of the "Dual Carbon" goals, effectively leveraging these two high-service-level modes of medium- and long-distance travel is critical for promoting rational division of roles between HSR and civil aviation within medium-distance travel ranges. By analyzing the characteristics of the domestic HSR and civil aviation passenger markets and their emission profiles, this article addresses key questions regarding structural adjustments in passenger transport and efforts to reduce pollution and carbon emissions. It also provides practical policy recommendations, offering valuable insights to support the achievement of the "Dual Carbon" strategic objectives.

Keywords: High-Speed Rail, Civil Aviation, "Dual Carbon" Strategy, Carbon Emissions, Lifecycle Emissions

This chaper is support by: Professor Mao Baohua, Ph.D. advisor and Executive Director of the China Center for Comprehensive Transportation Research at Beijing Jiaotong University.

Chapter IV Section of Structural Adjustment of Transportation (Passenger Transport)

27. What Changes Have Occurred in China's Passenger Transport Market Structure?

Overall, passenger travel in China primarily relies on three modes: road, rail, and civil aviation.

Between 2010 and 2023, against the backdrop of high-speed rail (HSR) and airport infrastructure development as well as sustained economic growth, these three travel modes exhibited the following characteristics:

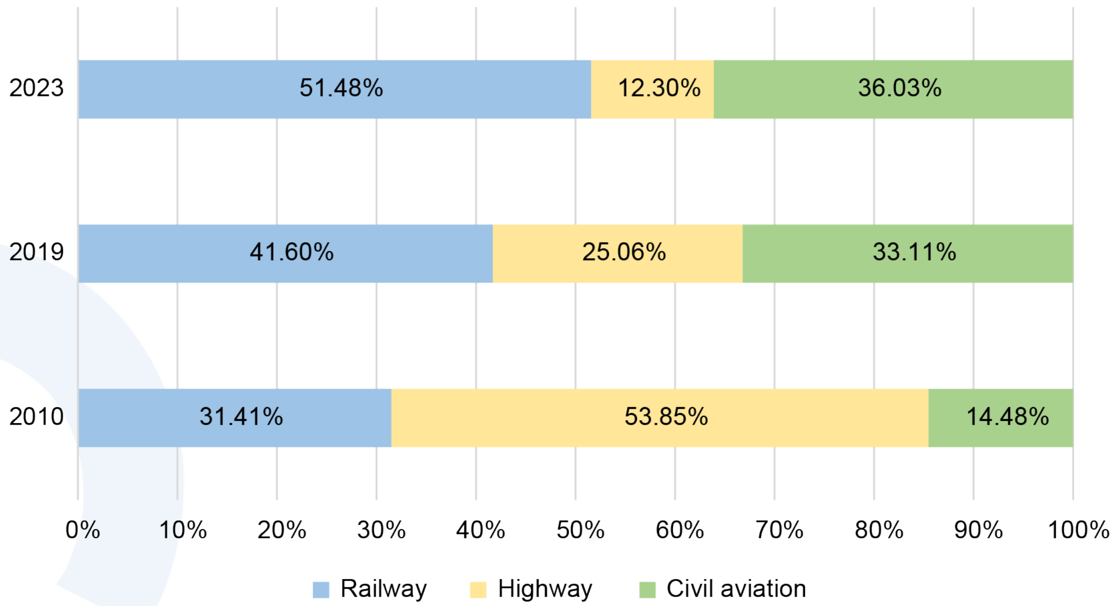
The share of passenger turnover by road transport continuously declined, dropping from 53.85% to 12.30%, falling below that of rail and civil aviation.

The share of passenger turnover by rail transport steadily increased, rising from 31.41% to 51.48%, making it the dominant mode of passenger transport.

The share of passenger turnover by civil aviation grew from 14.48% to 36.03%, becoming the second-largest mode of passenger transport.

This shift demonstrates a structural transformation in passenger transport: in 2010, road transport was the primary mode with rail as a supplement; by 2023, the structure had shifted to rail as the primary mode with road transport playing a supplementary role.

As critical national infrastructure, high-speed rail and civil aviation play a significant role in passenger travel. This article focuses on the developments in these two sectors and provides strategies and recommendations for optimizing the passenger transport structure of HSR and civil aviation under the "Dual Carbon" strategy.



Note: The data is sourced from the China Statistical Yearbook and the Ministry of Transport of the People's Republic of China.

Figure 40 Proportion of Passenger Turnover by Different Modes of Transportation in China in 2010, 2019, and 2023

28. What Are the Characteristics of Market Demand for High-Speed Rail and Civil Aviation?

In recent years, China has seen rapid improvements in both the quantity and quality of its transportation infrastructure. The scale of the high-speed rail (HSR) network and the number of civil aviation airports have steadily increased. In 2010, the operational mileage of high-speed rail in mainland China was 5,000 kilometers, accounting for only 5.6% of the total railway operational mileage. By the end of 2023, this figure had grown to 45,000 kilometers, making up 28.3% of the total railway operational mileage. Similarly, the number of certified transportation airports nationwide rose from 175 in 2010 to 259 in 2023. Between 2019 and 2022, the share of intercity travel by high-speed rail increased from 21.9% to 33.9%, while the share of civil aviation slightly decreased from 33.1% to 30.3%. Despite this, the combined share of these two modes consistently remained at around 60%, solidifying their status as the primary means of intercity travel.

(1) Characteristics of High-Speed Rail Passenger Market Demand

Since the opening of the Beijing-Tianjin Intercity Railway in 2008, China has officially entered the era of high-speed rail (HSR). Between 2008 and 2019, HSR passenger volume consistently increased, with an average annual growth rate of approximately 30% after 2012, as shown in Figure 41. From 2020 to 2022, the COVID-19 pandemic significantly impacted HSR passenger volume, causing a noticeable decline. However, in 2023, national railway passenger numbers reached 3.685 billion, with a total passenger turnover of 1,471.712 billion passenger-km. High-speed rail trains have become the backbone of railway passenger transport, with passenger volume on HSR trains accounting for approximately 70% of the total railway passenger volume.

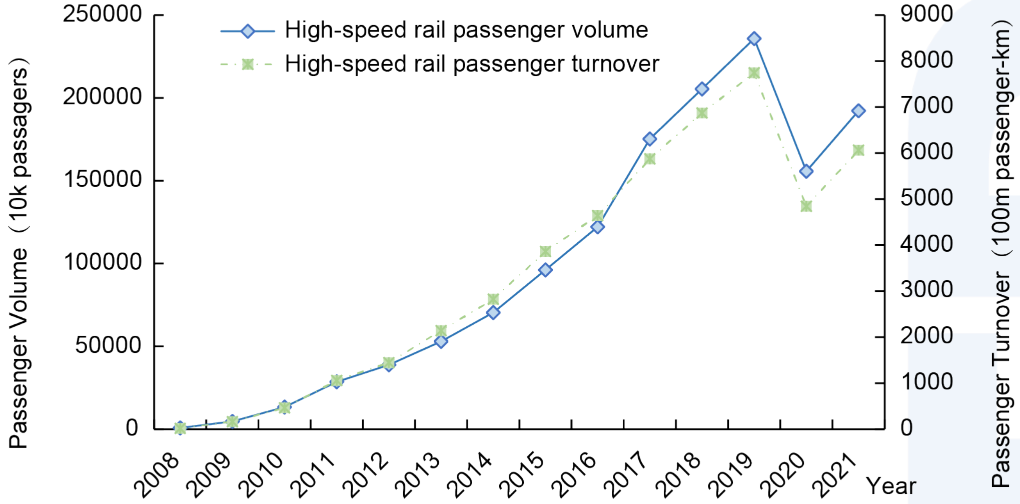


Figure 41 Changes in China's High-Speed Railway Passenger Volume and Passenger Turnover from 2008 to 2021

Per capita travel frequency refers to the ratio of annual passenger volume of a specific transportation mode within a region to the population of that region. It reflects both passengers' willingness to choose that mode and the service level it provides. As shown in Figure 42, the per capita travel frequency for high-speed rail (HSR) steadily increased from 0.01 trips in 2008 to 1.67 trips in 2019. This growth is attributed to the rapid expansion of the HSR network and its competitive advantages in the passenger market, including high punctuality, speed, and comfort, which have made it a preferred choice for travelers. In 2020, however, the per capita travel frequency for HSR dropped to 1.10 trips due to the outbreak of the COVID-19 pandemic.

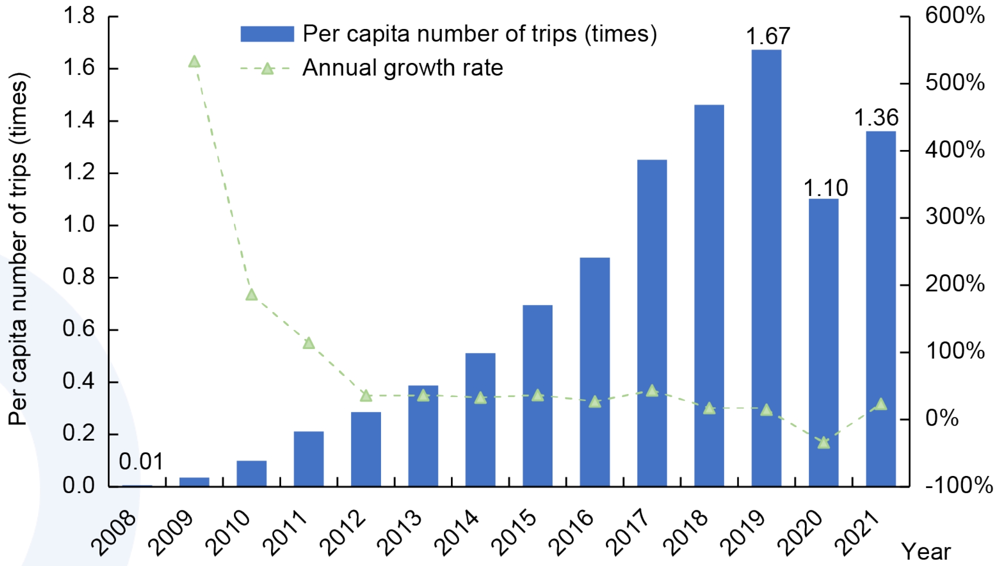


Figure 42 Per Capita Trips Taken by High-Speed Rail in China from 2008 to 2021

Average travel distance refers to the ratio of passenger turnover to passenger volume for a specific transportation mode within a region. It reflects the mode's optimal travel range and is influenced by factors such as connectivity, convenience, and speed.

Figure 43 Changes in the Average Travel Distance Per Passenger of High-Speed Rail in China from 2008 to 2021

Figure 43 illustrates the changes in the average travel distance of China's high-speed rail (HSR) from 2008 to 2021. The average travel distance for high-speed rail (HSR) in China surged from 212.5 kilometers in 2008 to 348.7 kilometers in 2009, and then steadily increased to 404.3 kilometers by 2013. From 2013 to 2020, the average travel distance showed a declining trend, reaching 311.2 kilometers in 2020. The main reason for this decline is the expanded competitiveness of HSR in the medium- and short-distance passenger transport market, which has attracted more travelers to choose high-speed rail for their trips.

(2) Characteristics of Civil Aviation Passenger Market Demand

Between 2008 and 2019, civil aviation passenger volume showed an overall upward trend, increasing from 190 million to 660 million passengers, with an annual growth rate of 11.9%. The passenger turnover in civil aviation rose from 288.28 billion passenger-kilometers to 1,170.53 billion passenger-kilometers, as shown in Figure 44. At present, although the passenger volume of civil aviation is relatively smaller compared to high-speed rail, it handles a larger turnover due to its significantly higher average travel distance.

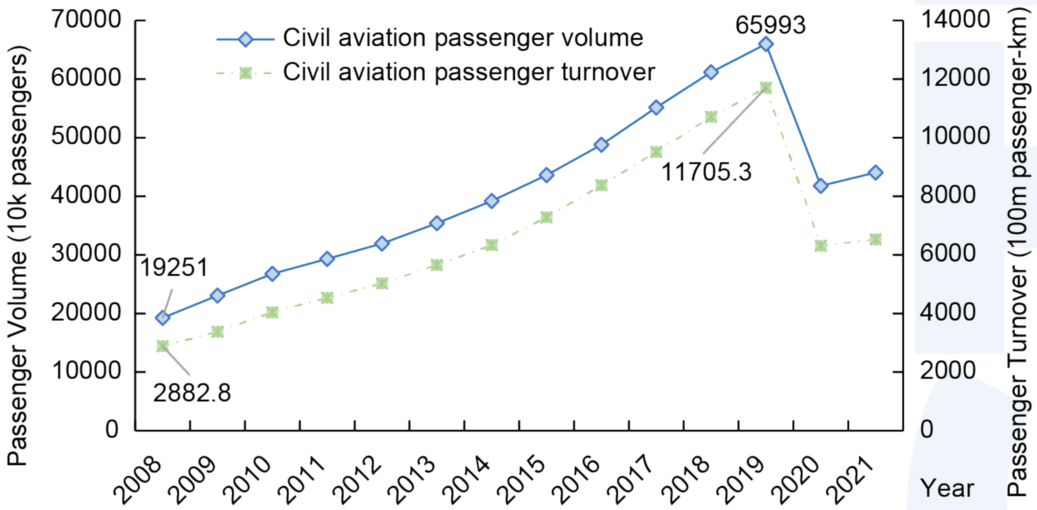


Figure 44 Changes in Passenger Volume and Passenger Turnover of China's Civil Aviation from 2008 to 2021

Per capita travel frequency in civil aviation can be characterized by the ratio of annual civil aviation passenger volume to the total population of the country in the same year. As shown in Figure 45, from 2000 to 2019, per capita travel frequency in civil aviation steadily increased, growing from 0.05 trips in 2000 to 0.47 trips in 2019. From 2011 to 2019, the annual growth rate remained at 10%, indicating a growing demand for civil aviation among passengers. Due to the impact of the pandemic, per capita travel frequency in civil aviation saw a significant decline in 2020, but it showed a slight recovery in 2021.

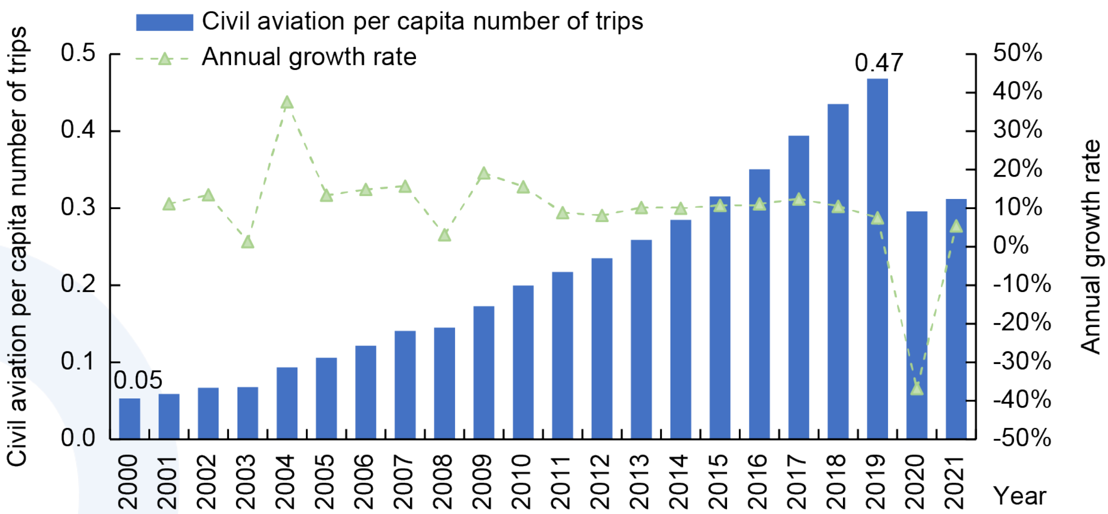


Figure 45 Average Number of Trips Per Capita By China's Civil Aviation from 2000 to 2021

The average travel distance in civil aviation (Excluding International Flights) can be characterized by the ratio of annual civil aviation passenger turnover to the total passenger volume in the same year. Figure 46 shows the changes in China's civil aviation average travel distance from 2000 to 2021. From 2000 to 2019, the average travel distance in civil aviation exhibited a fluctuating upward trend, increasing from 1,443.77 kilometers to 1,773.72 kilometers. This reflects that civil aviation primarily serves passengers traveling medium to long distances.

Before 2019, the demand scale in the civil aviation passenger market continued to rise steadily, with both passenger volume and turnover increasing. As economic levels continued to improve, per capita travel frequency also rose each year. Continuous construction of civil aviation infrastructure and optimization of the route network have, to some extent, increased the average travel distance in civil aviation.

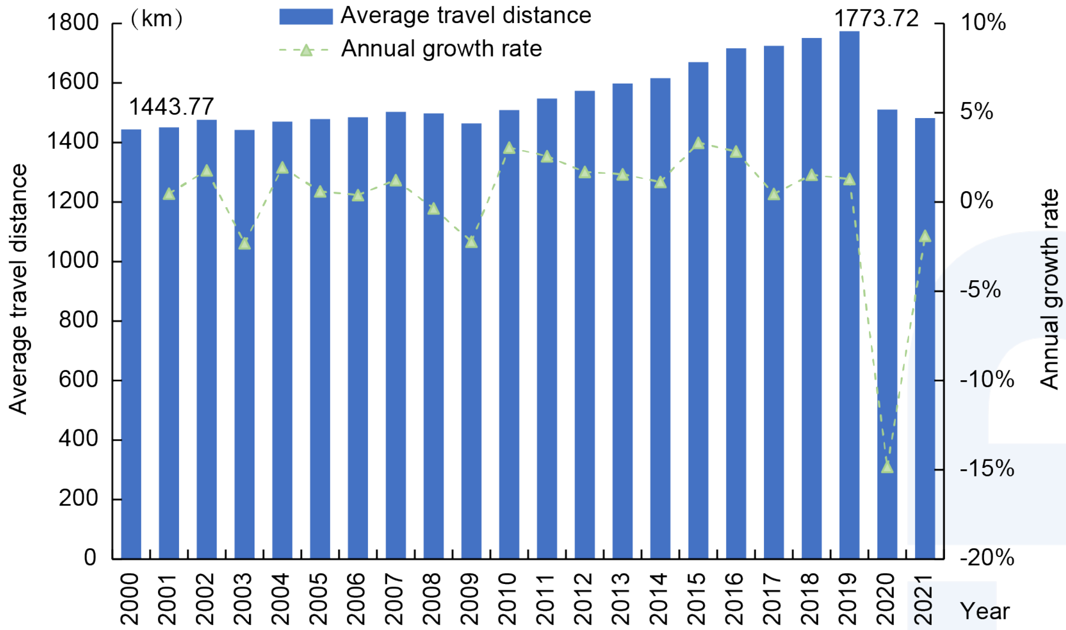


Figure 46 Changes in Average Travel Distance of China's Civil Aviation from 2000 to 2021

(3) Comparison of High-Speed Rail and Civil Aviation Passenger Markets

High-speed rail (HSR) competes with civil aviation due to its convenience and pricing advantages. The trends in the average travel distance for both high-speed rail and civil aviation are shown in Figure 47. With the gradual expansion of the HSR network, it has gained a competitive edge in the short- and medium-short distance markets. After reaching a peak of 404 kilometers in average travel distance in 2013, the figure gradually decreased to 328 kilometers by 2019. During the same period, civil aviation's share of the short-distance market shrank, while the proportion of long-distance travel increased. The average travel distance in civil aviation steadily rose from 1,598 kilometers to 1,774 kilometers. As a result, the rapid development of high-speed rail has allowed both HSR and civil aviation to leverage their competitive advantages in medium-short and medium-long distance markets, with their complementary relationship becoming increasingly evident.

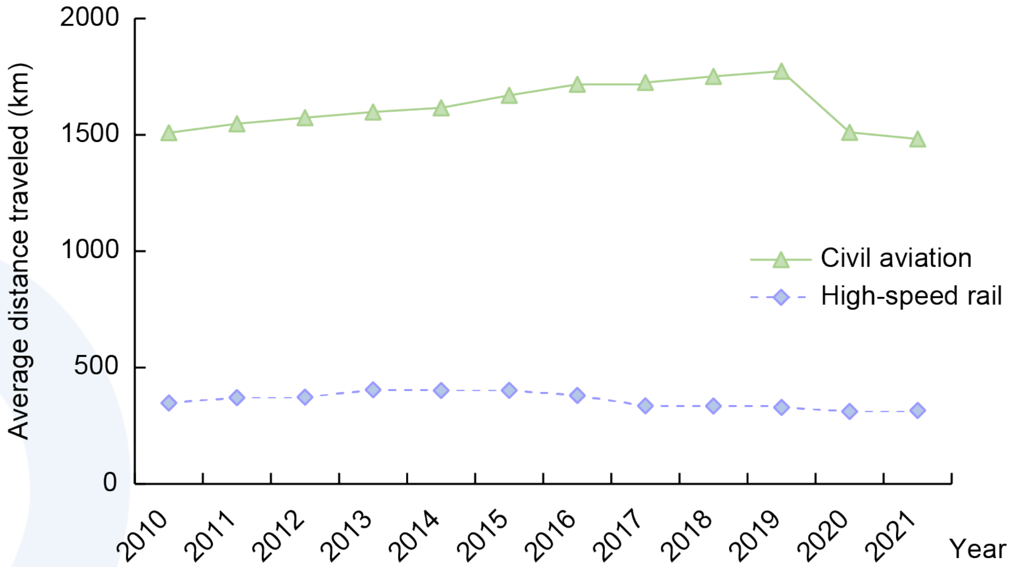


Figure 47 Comparison Chart of Average Travel Distance Between China's High-Speed Rail and Civil Aviation from 2010 to 2021

According to the statistics from *Civil Aviation from a Statistical Perspective*, the proportion of short-distance passenger transport (under 600 km) on major civil aviation routes in China has been declining. In 2010, the share of passenger transport on routes under 600 km was 16.0%, and by 2019, it had decreased to 8.3%. Compared to the eastern regions, the western regions are more dependent on civil aviation. The western region has more regional airports, and in 2019, the proportion of passenger transport on routes under 600 km exceeded 50%.

Based on data from VariFlight and combining information from Gcmap, on a typical workday in 2023, the total number of scheduled flights across Chinese airports was 16,429, of which 13,780 were direct flights, accounting for 83.9%, and 2,649 were connecting flights, accounting for 16.1%. The distribution of route distances for direct and connecting flights is shown in Figures 48 and 49, respectively.

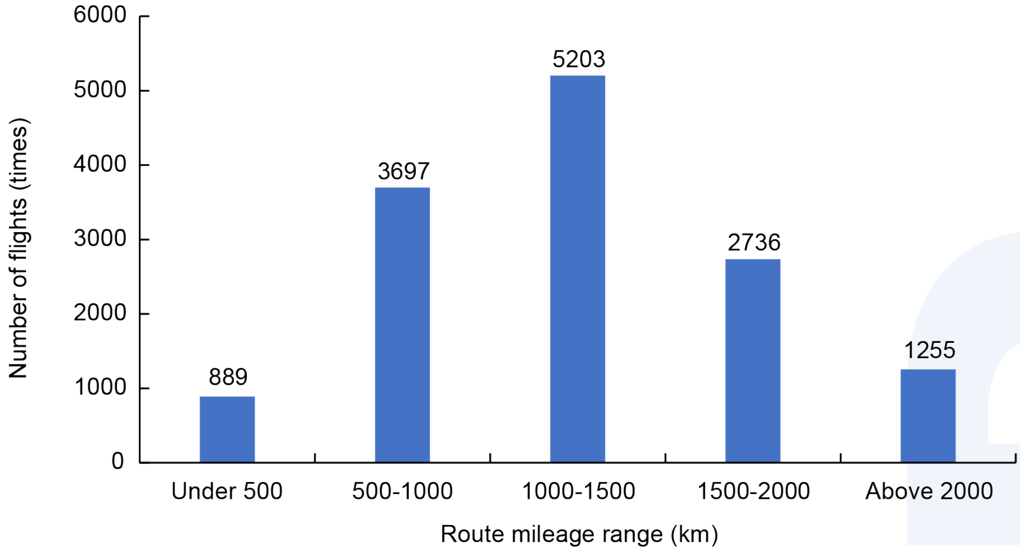


Figure 48 Mileage Distribution of China's Direct Flight Routes

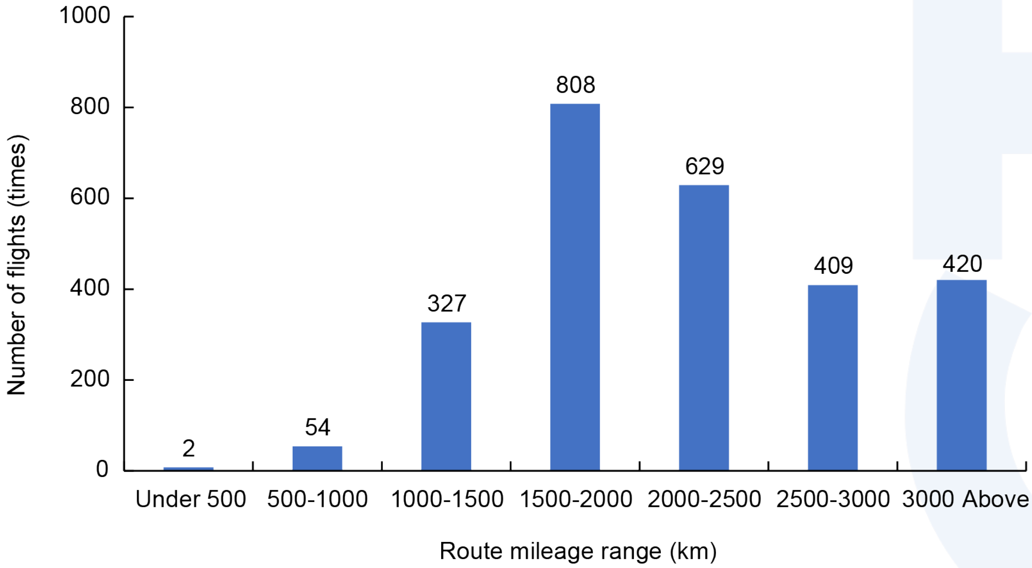


Figure 49 Mileage Distribution of China's Stopover Flight Routes

It can be observed that the route distances of direct flights in China are primarily distributed between 500 and 1,500 km, accounting for 64.6% of direct flights. Among them, flights with distances between 1,000 and 1,500 km account for the largest proportion, at 37.8%. Short-distance direct flights with distances under 500 km and long-distance direct flights over 2,000 km are relatively few, accounting for 6.5% and 9.1%, respectively. Additionally, the route distances for connecting flights are mainly concentrated between 1,500 and 2,500 km, accounting for 54.2% of connecting flights, with the largest proportion being flights with distances between 1,500 and 2,000 km, at 30.5%. Connecting flights primarily serve long-distance routes, with only two flights under 500 km, 54 flights between 500-1,000 km, and more than 55% of flights being over 2,000 km in distance.

(4) What are the regional characteristics of the high-speed rail and civil aviation passenger markets in China?

China's high-speed rail network exhibits a clear "dense in the east, sparse in the west" pattern, with the profitability of high-speed rail lines in the eastern regions being higher than in the western regions. According to statistics, profitable high-speed rail lines such as the Beijing-Shanghai, Shanghai-Nanjing, Nanjing-Hangzhou, Guangzhou-Shenzhen-Hong Kong, Shanghai-Hangzhou, and Beijing-Tianjin lines are all located in eastern China, while many other lines are operating at a loss. This is due to differences in topography, population density, and economic development levels. In addition, China's high-speed rail ticket pricing has limited elasticity, and the fare rates are mismatched with regional economic development, leading to lower passenger occupancy rates and underutilized capacity on some lines.

Table 13 provides the per capita disposable income and corresponding average ticket fare rates for high-speed rail lines in various provinces in different regions of China in 2021. According to the *China Statistical Yearbook 2022*, the national average per capita disposable income in 2021 was 35,128 yuan.

Table 13 Per Capita Disposable Income and Average Fare Rate of High-Speed Rail Lines in Selected Provinces in 2021

Province	Per capita disposable income (Yuan)	Per capita disposable income of the province/ National average per capita disposable income	Average route traffic price rate (Yuan /km)		
			Second-class	First-class	Business-class
Guangdong	44,993	1.28	0.43	0.69	1.35
Shandong	35,705	1.02	0.42	0.68	1.33
Liaoning	35,112	1.00	0.43	0.70	1.32
Henan	26,811	0.76	0.44	0.70	1.33
Yunnan	25,666	0.73	0.44	0.72	1.29
Gansu	22,066	0.63	0.40	0.63	1.23

It can be observed that in western regions such as Gansu and Yunnan, as well as the central region of Henan, the annual per capita disposable income is only 22,000 to 27,000 yuan, which is 60% to 75% of the national average. In eastern regions like Shandong and Guangdong, the per capita disposable income is 35,700 yuan and 45,000 yuan respectively, with Guangdong exceeding the national average by 28%. From the perspective of average fare rates, the average fare rates for second-class seats on lines in different provinces generally range from 0.40 to 0.45 yuan/km. The difference in fare rates between lines in Gansu and Guangdong, which have the largest disparity in per capita disposable income, is less than 0.05 yuan/km. In Yunnan, which has a relatively lower economic level, the fare rate for second-class seats is even higher than that in relatively developed provinces such as Guangdong and Shandong. The pricing strategy for high-speed rail tickets is basically unified nationwide, but its attractiveness to residents in less developed areas needs to be enhanced.

Based on the role played by airports in the civil aviation transportation network system, they are generally classified into three categories: hub airports, trunk airports, and regional airports. The passenger flow volume of these three types of airports generally decreases in sequence. By analyzing the differences in fare rates between hub and trunk airports and regional airports, and compiling statistics on the fare rate distribution of 169 hub and trunk routes and 49 regional routes, as shown in Table 14.

Table 14 Comparison of Fare Rate Distribution for Selected Routes at Hub, Trunk, and Regional Airports in Typical Provinces

Traffic price rate range (Yuan/km)	Hub and trunk airport		Feeder airport	
	Frequency	Proportion	Frequency	Proportion
0.2-0.4	21	12.4%	0	0.0%
0.4-0.6	57	33.7%	11	22.4%
0.6-0.8	38	22.5%	15	30.6%
0.8-1.0	25	14.8%	12	24.5%
1.0-1.2	14	8.3%	5	10.2%
1.2-1.4	1	0.6%	0	0.0%
1.4-1.6	2	1.2%	3	6.1%
1.6-1.8	3	1.8%	1	2.0%
1.8-2.0	2	1.2%	0	0.0%
Above 2.0	6	3.6%	2	4.1%
Sum	169	100%	49	100%

As can be seen from Table 14, the fare rates at hub and trunk airports are relatively lower. Specifically, 83.4% of the fare rates at hub and trunk airports fall within the range of 0.2-1.0 yuan/km, while 87.8% of the fare rates at regional airports fall within the range of 0.4-1.2 yuan/km. The largest proportion of fare rates at hub and trunk airports is in the range of 0.4-0.6 yuan/km, while for regional airports, it is in the range of 0.6-0.8 yuan/km. Calculations indicate that the average fare rate for the 169 hub and trunk routes is 0.754 yuan/km, while the average fare rate for the 49 regional routes is 0.896 yuan/km. Regional airports serve as important external transportation facilities in economically underdeveloped or sparsely populated areas of China, and their relatively higher fare rates do not match the level of regional economic development and per capita income.

Figures 50 and 51 present statistics on the average fare rate levels corresponding to some high-speed rail and civil aviation trips in six provinces listed in Table 13. For high-speed rail, the second-class seat fares are taken as examples, and for civil aviation, the economy class fares are taken as examples.

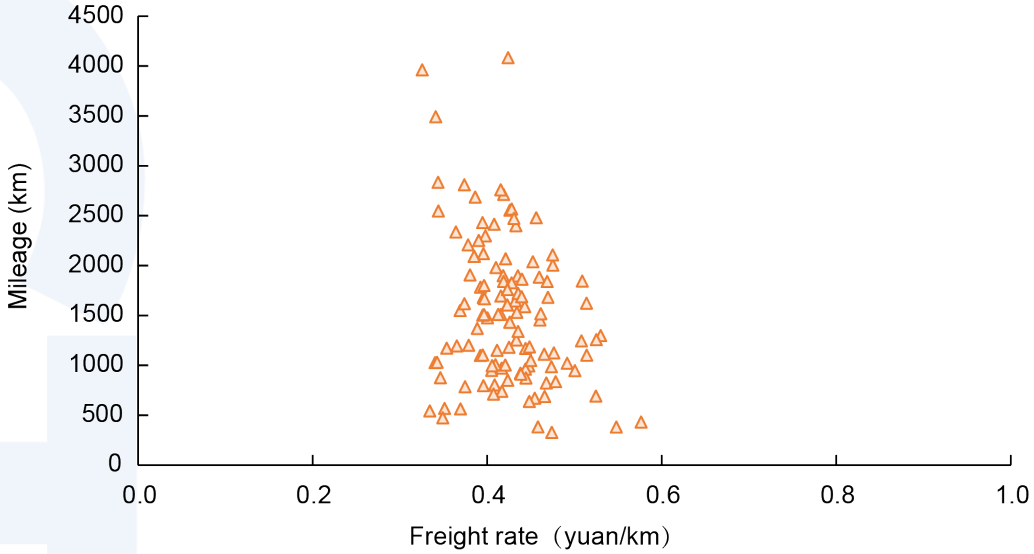


Figure 50 Distribution of Second-Class Seat Fare Rates on Typical High-Speed Rail Lines

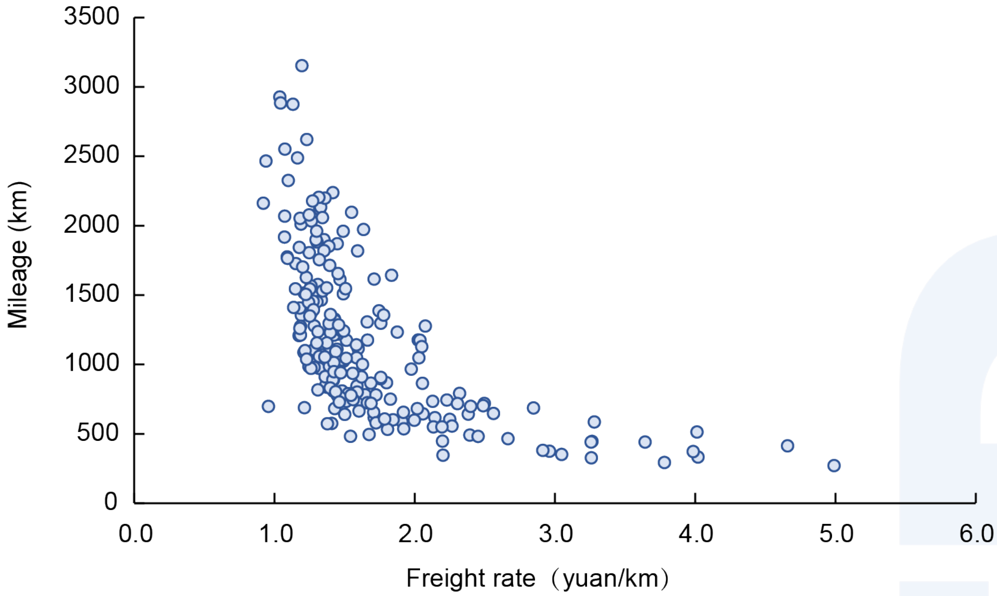


Figure 51 Distribution of Economy Class Fare Rates on Typical Flights

From Figures 50 and 51, it can be seen that the high-speed rail fare rate is generally distributed between 0.35-0.50 yuan/km, while the civil aviation fare rate shows a trend where the shorter the distance, the higher the fare rate. For short-distance civil aviation, the fare rate is distributed between 1.5-5.0 yuan/km, indicating weaker competitiveness. For long-distance travel, the high-speed rail fare rate remains within the range of 0.35-0.50 yuan/km, lower than the civil aviation fare rate of 1.0-1.5 yuan/km. Since most civil aviation tickets are sold at discounted prices, the discount rate has a significant impact on civil aviation's competitiveness. Civil aviation is more competitive when the discount rate is below 50%.

Figure 52 shows the relationship between the civil aviation discount ticket fare rate (including fuel and airport fees) and distance.

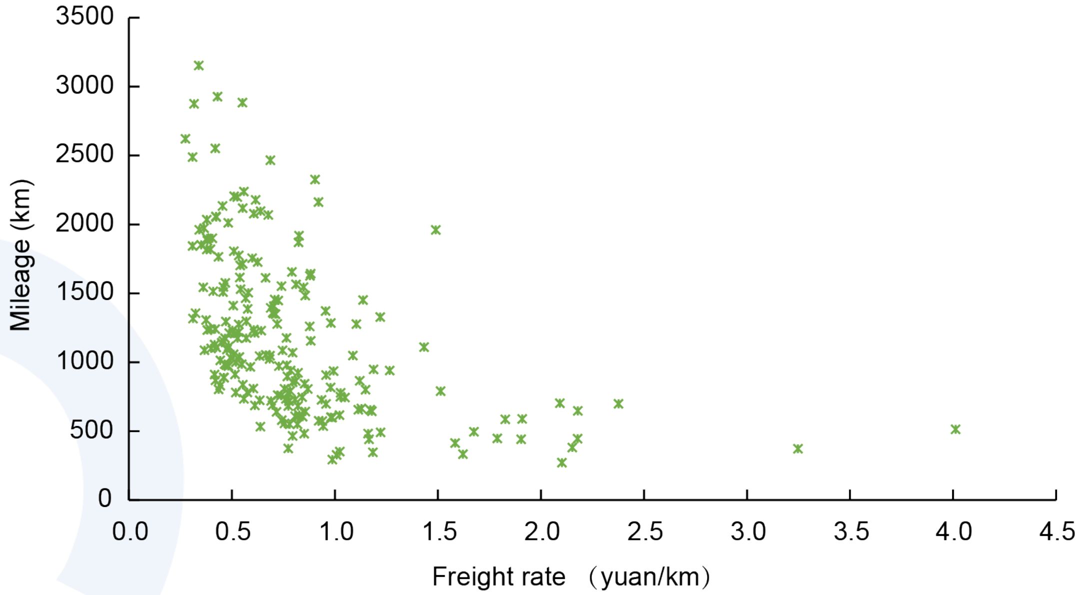


Figure 52 Distribution of Discounted Economy Class Fare Rates on Typical Flights

It is evident that the discounted civil aviation fare rates are mostly between 0.3-1.0 yuan/km, offering certain competitiveness, with some flights even having a fare rate lower than high-speed rail.

Figure 53 shows the discount rate levels for typical flights; among them, 28.1% of flights have a discount rate between 20%-30%, and 18.9% have a discount rate between 30%-40%. Additionally, 70.5% of flights have a discount rate exceeding 50%.

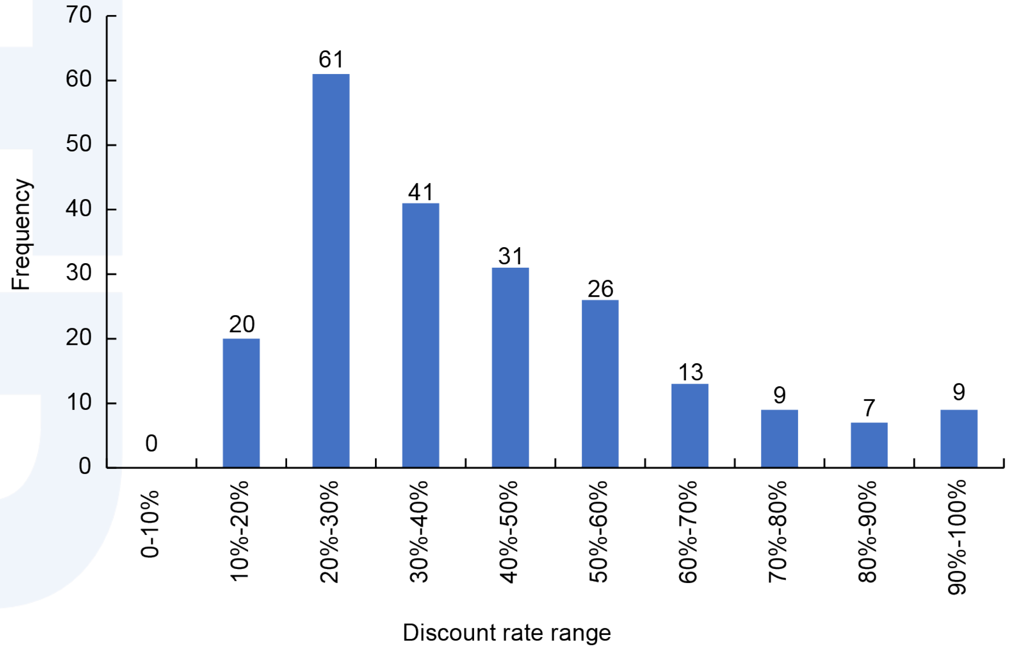


Figure 53 Distribution Chart of Discount Rates on Typical Flights

Considering the typical economy class fare rate range (1.0-2.5 yuan/km) for flights, when the discount rate is 50%, the fare rate, including fuel and airport construction fees, drops to 0.6-1.3 yuan/km. With a 30% discount rate, the fare rate decreases to 0.35-0.90 yuan/km, which is very close to the average fare rate for typical high-speed rail second-class seats (0.35-0.50 yuan/km), making it highly competitive.

29. What is the carbon emission level throughout the entire process for high-speed rail and civil aviation?

High-speed trains are powered by electricity, and their main source of carbon emissions comes from the upstream power generation. In addition to the traction phase, the total carbon emissions of high-speed rail also need to consider emissions from stations and maintenance stages.

Under the current power generation structure, the carbon emission factor for high-speed rail passenger transport is approximately 30.5 gCO_2 per passenger-kilometer, while for civil aviation, the carbon emission factor is 95.3 gCO_2 per passenger-kilometer, more than three times higher than that of high-speed rail. In 2019, the combined carbon emissions of high-speed rail and civil aviation amounted to 133 million tons, accounting for 14.8% of total transport sector carbon emissions (with the total emissions according to IEA being 901 million tons). According to IEA statistics, from 2010 to 2019, the carbon emission growth rate in China's transport sector was 58%.

(1) Energy Consumption and Emission Efficiency of High-speed Railways

i. Calculation Method for Energy Consumption and Carbon Emissions Throughout the Entire Process of High-speed Railway

The carbon emissions from the station and section system include emissions from stations, vehicle bases, and other facilities. Specifically, the carbon emissions from the station system refer to the emissions generated by various facilities and equipment required to maintain the normal operation of the station due to energy consumption. These emissions include those from ticketing, ticket inspection, inquiries, stairs and elevators, lighting, air conditioning, and other services.

The carbon emissions from the high-speed rail maintenance system encompass seven major areas: track engineering, bridge engineering, embankment engineering, tunnel engineering, electrification engineering, train maintenance and repair, and station equipment maintenance.

On the other hand, the operational energy consumption of high-speed rail can be divided into traction energy consumption and non-traction energy consumption. Traction energy consumption refers to the total energy consumed for the traction of locomotives or high-speed trains, while non-traction energy consumption refers to the energy consumed by equipment other than for traction, including heating, ventilation, air conditioning, lighting, signaling, communication, and water supply and drainage systems.

The energy consumption calculation method for the high-speed rail operation phase is shown in formulas (1) - (3).

$$Q = Q_s + Q_{ns} \quad (1)$$

In formulas (1) - (3), Q represents the total energy consumption during the high-speed rail operation phase, in kW·h; Q_s represents the energy consumption of the traction system, in kW·h; Q_{ns} represents the energy consumption of the non-traction systems, in kW·h; Q_{dc} represents the energy consumption of the high-speed train for traction operation, in kW·h; Q_{zd} represents the energy consumption of the station and section systems, in kW·h; Q_{yh} represents the energy consumption of the maintenance system, in kW·h; and α represents the traction power supply loss rate.

To assess the carbon emissions from the high-speed rail operation phase from a full transportation process perspective, the following formula can be used:

$$E_{yy} = E_{dc} + E_{zd} + E_{yh} \quad (4)$$

In formula (4), E_{yy} represents the total carbon emissions during the high-speed rail operation phase, in tCO_2; E_{dc} represents the carbon emissions from the traction system, in tCO_2; E_{zd} represents the carbon emissions from the station and section systems, in tCO_2; and E_{yh} represents the carbon emissions from the maintenance system, in tCO_2.

ii. Analysis of High-Speed Rail Full-Process Carbon Emissions

Table 15 organizes data from the *China Railway Yearbook (2018-2020)*, detailing the total traction power supply and high-speed rail traction power supply for various years. From 2017 to 2019, the traction power supply for high-speed rail increased annually, with its share of total traction power supply rising from 37.6% to 43.6%. This increase is attributed to the growing proportion of high-speed rail passenger turnover within the total railway passenger turnover. Specifically, from 2017 to 2019, the share of high-speed rail passenger turnover in total railway passenger turnover rose from 43.7% to 52.7%.

Table 15 Traction Power Supply and Its Proportion in Chinese Railways and High-Speed Railways

Indicator	2017	2018	2019
Total traction power supply (100 million kWh)[102]	664.07	735.96	802.77
Electric locomotive traction power consumption (100 million kWh)[103]	394.91	413.42	431.26
Electric locomotive traction power supply (100 million kWh)[104]	414.43	436.42	452.63
High-speed rail traction power supply (100 million kWh)[105]	249.63	299.55	350.15
Proportion of high-speed rail traction power supply	37.6%	40.7%	43.6%

The research shows that the carbon emissions from high-speed railway stations primarily originate from electricity consumption[106]. Among the carbon emissions during the operation of high-speed rail, traction power supply contributes 86.2%, followed by station operations at 11.2%[107]. Based on the data of power supply during the traction phase of high-speed rail in Table 15 and the power supply loss rate, the electricity consumption during the traction phase and the entire transportation process from 2017 to 2019 can be calculated[108], as shown in Table 16. The estimated carbon emissions during the traction phase and the entire transportation process of China's high-speed rail during the operation period, as well as the carbon emissions per passenger kilometer, are presented in Table 17.

[102] Data Source: China Railway Yearbook (2018-2020).

[103] The calculations are based on the data of electric locomotive workload and power consumption per unit workload of electric locomotives from the China Railway Yearbook (2018-2020).

[104] The traction power supply for electric locomotives is calculated as: Traction power supply for electric locomotives = Electricity consumption for electric locomotive traction / (1 - Power supply loss rate). The power supply loss rate data is sourced from the China Railway Yearbook, with the rates for 2017, 2018, and 2019 being 4.71%, 5.27%, and 4.72% respectively.

[105] The traction power supply for high-speed rail is calculated as: Traction power supply for high-speed rail = Total traction power supply - Traction power supply for electric locomotives.

[106] REN Nanqi, XU Zhicheng, LU Yintao, et al. Thinking on Carbon Emission Characteristics and Emission Reduction Path in Railway Operation Period [J]. *Railway Standard Design*, 2022, 66(07): 1-6.

[107] CUI Zhanwei. Analysis of Carbon Emissions during the Operation Phase of High-Speed Rail [D]. Shijiazhuang Tiedao University, 2019.

[108] Total electricity consumption during high-speed rail transportation = Electricity consumption for high-speed rail traction / 86.2%.

Table 16 Electricity Consumption During the Traction Phase and the Entire Transportation Process of China's High-Speed Railways

Indicator	2017	2018	2019
Power supply loss rate	4.71%	5.27%	4.72%
High-speed rail traction power supply (100 million kWh)	237.87	283.76	333.62
High-speed rail total electricity consumption (100 million kWh)	275.95	329.19	387.03

Table 17 Carbon Emissions and Carbon Emissions Per Passenger-Kilometer Of China's High-Speed Railways

Indicator	2017	2018	2019
High-speed rail total carbon emissions (ten thousand tCO_2)	1,683.57	2,008.39	2,361.27
Carbon emissions in traction stage of high-speed rail (ten thousand tCO_2)	1,451.24	1,731.22	2,035.42
Passenger turnover of high-speed rail (100 million person-kilometers)	5,875.6	6,871.9	7,746.7
Carbon emissions per unit passenger turnover in the whole process (gCO_2/ person-km)	28.65	29.23	30.48
Carbon emissions per unit of passenger turnover in traction phase (gCO_2/ person-km)	24.70	25.19	26.27

As can be seen from Table 17, the carbon emissions per passenger kilometer of high-speed rail in China have been increasing continuously from 2017 to 2019. In 2017, 2018, and 2019, the operating mileage of China's high-speed rail was 25,200 km, 29,900 km, and 35,400 km respectively, with an average annual growth rate of 12.0%. However, the average annual growth rate of passenger transport turnover was only 9.7%, which led to an increase in carbon emissions per passenger kilometer during the entire process over these three years, ranging from 28.65 to 30.48 gCO_2/passenger-km. If only the traction phase is considered, the carbon emissions per passenger kilometer of high-speed rail range from 24.70 to 26.27 gCO_2/passenger-km. In comparison, the annual carbon emissions per unit of high-speed rail during the entire process increased by 3.95 to 4.21 gCO_2/passenger-km (approximately 16%) compared to the traction phase. The additional carbon emissions originate from energy-consuming stations and depots such as railway stations and vehicle bases, as well as the renewal and maintenance of lines.

A significant amount of research has been conducted on carbon emissions during train operation stages both domestically and internationally. Table 18 compares the carbon emissions per passenger kilometer during the traction operation stage of high-speed rail in typical countries.

Table 18 Carbon Emissions Per Passenger-Kilometer During the Operation Phase of High-Speed Railways in Typical Countries in 2019

Nation	Carbon Emissions Per Unit of Passenger Turnover During Operation of HSR (gCO_2/ person-km)	Proportion of Thermal Power	Electricity Emission Factor (gCO_2/ kwh)
China	26.27[109]	68.88%[110]	610.10[111]
France	1.73[112]	3.76%[113]	55.00[114]
Germany	20.47[115]	43.01%[116]	353.00[117]
Japan	19.6[118]	75.00%[119]	444.00[120]

109 Calculated by the author

110 Data source: China Electric Power Yearbook - 2020.

111 Data source: "Notice on Key Tasks for Improving the Management of Greenhouse Gas Emission Reporting by Enterprises in 2022" (Huan Ban Qi Hou Han [2022] No. 111) issued by the General Office of the Ministry of Ecology and Environment.

112 Data Source: SNCF official website. https://www.sncf-reseau.com/fr/atouts-rail-transport-responsable-et-durable.

113 Data source: "Chiffres clés de l'énergie Édition 2021" published by the French Ministry for Ecological Transition and Territorial Cohesion.

114 Data Source: eDF, https://www.edf.fr/groupe-edf/agir-en-entreprise-responsable/responsabilite-societale-dentreprise/plus-loin-dans-la-reduction-des-emissions-de-co2.

115 Chiara B D, Franco D D, Coviello N, et al. Comparative specific energy consumption between air transport and high-speed rail transport: A practical assessment[J]. Transportation Research Part D: Transport and Environment, 2017, 52(A): 227-243.

116 Data Source: Bruttostromerzeugung in Deutschlan published by Federal Statistical Office of Germany

117 Data Source: Umweltbundesamt. Entwicklung der spezifischen treibhausgas-emissionen des Deutschen strommix in den jahren1990 –2021 published by Federal Statistical Office of Germany

118 Data Source: the official website of Japan's Ministry of Land, Infrastructure, Transport and Tourism, https://www.mlit.go.jp/sogoseisaku/environment/sosei_environment_tk_000007.html, https://www.mlit.go.jp/tetudo/shinkansen/shinkansen3_2.html.

119 Data Source: The official website of this Electrical Utilities Association, https://www.fepc.or.jp/smp/nuclear/state/setsubi/index.html.

120 Data Source: the official website of the Japan Electrical Utilities Low-Carbon Society Agreement Council, https://www.ene100.jp/zumen/2-1-16.

As can be seen from Table 18, among the four typical countries, China has the highest carbon emissions per passenger kilometer during the traction operation stage of high-speed rail. This is due to the high proportion of thermal power in China's power generation mix, with a significant share coming from coal-fired power generation. In contrast, the proportions of thermal power in France and Germany are far lower than in China. Although the proportion of thermal power in Japan is high, the share of gas-fired power generation within thermal power reaches 49.33%, which is higher than the corresponding share in China (4.86%).

Figure 56 presents the forecast results of China's power generation mix in 2030, 2040, and 2050 by the Energy Information Administration (EIA) of the United States, as well as the predicted carbon emissions per passenger kilometer during the operation stage of China's high-speed rail based on these forecasted power generation mix values.

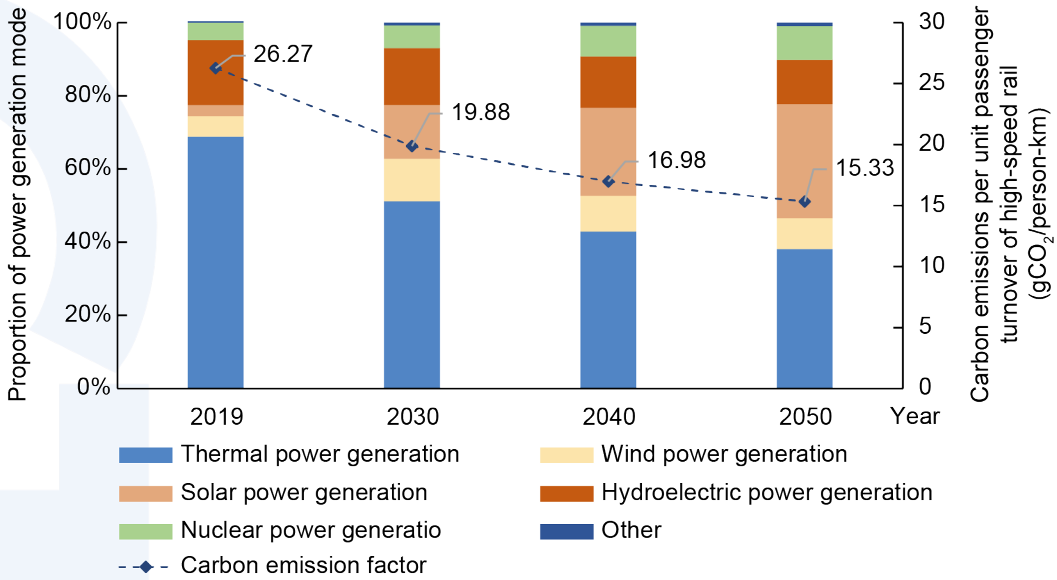


Figure 54 Forecast of Carbon Emissions per Passenger Turnover during China's High-Speed Rail Operation

According to the forecast values published by the Energy Information Administration (EIA), the proportion of thermal power will decrease significantly in the future, while the proportions of solar and nuclear power generation will increase substantially. Based on this projection, the carbon emissions per passenger kilometer for China's high-speed rail operations in 2050 are estimated to be 15.33 CO_2/passenger-km, representing a 41.6% reduction compared to 2019.

(2) Energy Consumption and Emission Efficiency of Civil Aviation

From 2015 and 2019, the proportion of passenger turnover handled by civil aviation increased from 24% in 2015 to 33% in 2019, and the average travel distance also showed an upward trend; this indicates a continuous improvement in the travel patterns of Chinese residents. Civil aviation aircraft use fossil fuel aviation kerosene as the primary energy source, which generates significant carbon emissions.

i Overview of Energy Consumption and Carbon Emissions During Civil Aviation Flights

Combining the consumption of aviation kerosene in civil aviation, a top-down approach is used to calculate the carbon emissions from energy consumption during passenger flights in China's civil aviation (excluding the kerosene refining process, only the fuel combustion process is considered) [121], as shown in Figure 57. Here, the lower heating value of aviation kerosene is taken as 43.07 GJ/ton, the carbon content per unit heat value is 0.0196 tons of carbon per GJ, and based on a carbon oxidation rate of 98%, the carbon emission factor for aviation kerosene is determined to be 3.033 tCO_2/t.

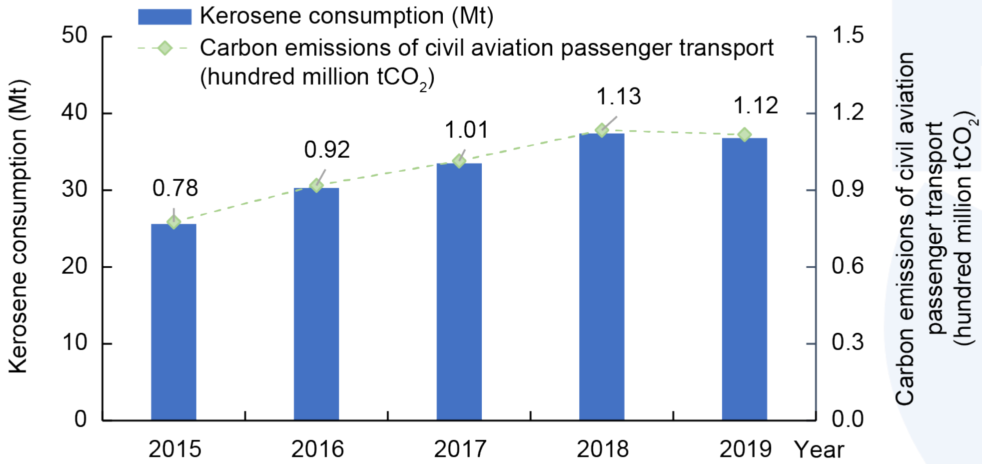


Figure 55 Aviation Kerosene Consumption and Carbon Emissions from Civil Aviation Passenger Flights in China from 2015 to 2019

As can be seen from Table 18, among the four typical countries, China has the highest carbon emissions per passenger kilometer during the traction operation stage of high-speed rail. This is due to the high proportion of thermal power in China's power generation mix, with a significant share coming from coal-fired power generation. In contrast, the proportions of thermal power in France and Germany are far lower than in China. Although the proportion of thermal

[121] The data on aviation kerosene consumption for the calculation is sourced from Wang Qingyi's "2020 Energy Data", while the fossil fuel parameters are derived from the "Guidelines for Calculating and Reporting Greenhouse Gas Emissions from Power Generation Facilities".

power in Japan is high, the share of gas-fired power generation within thermal power reaches 49.33%, which is higher than the corresponding share in China (4.86%).

Figure 56 presents the forecast results of China's power generation mix in 2030, 2040, and 2050 by the Energy Information Administration (EIA) of the United States, as well as the predicted carbon emissions per passenger kilometer during the operation stage of China's high-speed rail based on these forecasted power generation mix values.

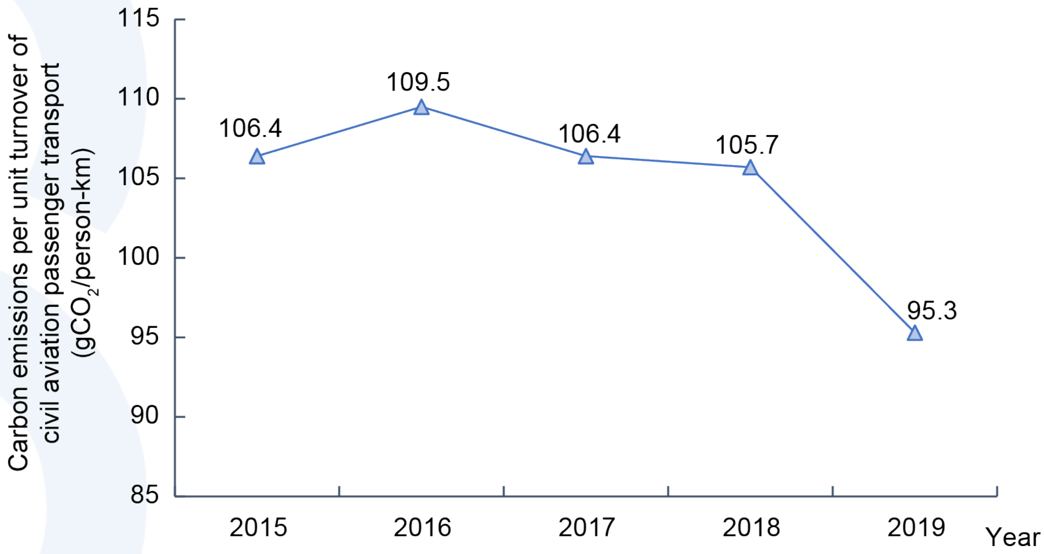


Figure 56 Carbon Emissions per Passenger Turnover from Civil Aviation Passenger Flights in China from 2015 to 2019

Obviously, in 2019, the carbon emissions per passenger kilometer during flight operations were 95.3 gCO_2/pkm, representing a 14.9% decrease compared to 2016. This reduction can be attributed to the gradual increase in civil aviation load factors; between 2010 and 2019, the average load factor of China's civil aviation rose from 80.87% to 86.39%. Additionally, the average transport distance has increased, with the average distance traveled by China's civil aviation flights rising from 1,509 km in 2010 to 1,774 km in 2019. Since carbon emissions are more intense during the LTO phase of flights (landing and take-off, including the processes of takeoff, climb, approach, and taxiing), an increase in the average cruise distance leads to a decrease in carbon emissions per passenger kilometer during flight operations. In 2010, China had 1,597 transport aircraft, which increased to 3,818 in 2019; newer aircraft have reduced the average age of the fleet and the carbon emission intensity.

Table 19 lists the civil aviation passenger transport indicators of China and some developed countries, including the level of carbon emissions per passenger kilometer during flight operations for each country.

Table 19 Comparison of Carbon Emissions Per Passenger-Kilometer During Passenger Flights of Civil Aviation in Typical Countries in 2019

Nation	Average attendance	Average distance (km)	Flight hours (10,000 h)	Carbon emissions per unit of passenger turnover during flight (gCO2/ person-km)
China	86.39%[122]	1,774[123]	1,231.1[102]	95.3[124]
America	83.50%[125]	1,153[126]	2,180.1[127]	147.8[128]
Britain	85.90%[129]	1,923 (International inclusive)[109]	321.4[109]	103.2[130]
Japan	73.80%[131]	986[111]	212.4[132]	98.0[133]

[122] Data source: Civil Aviation in Statistics 2020

[123] The average travel distance is the ratio of annual passenger turnover to annual passenger volume (the same applies hereinafter). The data on passenger volume and turnover are sourced from "China Statistical Yearbook 2020".

[124] The calculation is based on the civil aviation energy consumption data published in Wang Qingyi's "2020 Energy Data" and the civil aviation passenger turnover data published in "China Statistical Yearbook 2020".

[125] Data Source: the official website of the U.S. Department of Transportation, https://www.transtats.bts.gov/Data_Elements.aspx?Data=5.

[126] The data on passenger volume and turnover are sourced from the official website of the U.S. Department of Transportation, https://www.transtats.bts.gov/Data_Elements.aspx?Data=5, and https://www.bts.gov/content/us-passenger-miles.

[127] Data Source: the official website of the U.S. Department of Transportation, https://www.bts.gov/content/us-general-aviation-safety-data.

[128] Data Source: the official website of the U.S. Environmental Protection Agency (EPA), https://www.epa.gov/greenvehicles/archives-fast-facts-us-transportation-sector-greenhouse-gas-emissions.

[129] Data Source: the official website of the United Kingdom Civil Aviation Authority, https://www.caa.co.uk/Documents/Download/4007/41d1c005-464b-4ae2-967c-40ab4e723a0c/539.

[130] Data Source: "Aviation, Decarbonisation and Climate Change Published Monday" released by the UK Parliament.

[131] Data Source: the official website of Japan's Ministry of Land, Infrastructure, Transport and Tourism, https://www.mlit.go.jp/report/press/joho05_hh_000800.html.

[132] Data Source: the official website of Japan's National Institute of Information and Statistics, https://www.e-stat.go.jp/stat-search/?page=1.

[133] Data Source: the official website of Japan's Ministry of Land, Infrastructure, Transport and Tourism, https://www.mlit.go.jp/sogoseisaku/environment/sosei_environment_tk_000007.html.

As shown in Table 19, the carbon emissions per passenger kilometer during China's civil aviation passenger flights are lower than those of the United States, the United Kingdom, and Japan. The relatively high carbon emissions per passenger kilometer during U.S. civil aviation passenger flights can be attributed to its lower average transport distance and the large number of general aviation aircraft and small transport aircraft in the United States, which have smaller passenger capacities and therefore higher carbon emissions per passenger kilometer. Despite Japan's lower average load factor and average transport distance, its carbon emissions per passenger kilometer during flights are lower than those of the United States and the United Kingdom. According to statistics from JAPAN AIRLINES, the majority of civil aviation aircraft in Japan are wide-bodied, with a share of 52% in 2022 (compared to 12% in China). Wide-bodied aircraft have larger passenger capacities, resulting in lower carbon emissions per passenger kilometer during flights at the same load factor.

ii Analysis of carbon emission levels throughout the entire civil aviation passenger transport process

The carbon emissions throughout the entire civil aviation passenger transport process include emissions from aircraft flight stages and non-aircraft emission sources at airports; carbon emissions during flight stages encompass not only those from fuel combustion but also those from the aviation fuel refining process.

- Carbon Emissions from Aviation Kerosene Refining Process

Aviation kerosene, gasoline, diesel, and other fuels belong to the refined oil-petroleum products sub-industry within the petrochemical industry. According to the "Report on Pathways to Carbon Peaking and Carbon Reduction in China's Petrochemical Industry" by the Institute of Energy, Peking University, in 2022, the carbon emission per ton of product in the refining sub-industry of China's petrochemical industry was 0.325 tCO_2/t in 2021. In 2019, China's civil aviation consumed 36.84 million tons[134] of aviation kerosene, resulting in an estimated 11.973 million tons of carbon dioxide emissions during the refining stage in the same year.

When considering carbon emissions from the aviation kerosene refining process, the total carbon emissions during the civil aviation passenger flight stage amounted to 124 million tons, with carbon emissions per passenger kilometer at 105.5 gCO_2/passenger-km.

- Estimation of Airport Carbon Emissions

[134] WANG Qingyi. China Energy Data 2020 [R]. Green Innovation and Development Center, 2021.

In existing research, airport carbon emissions encompass emissions from aircraft landing and take-off (LTO) processes, terminal buildings, and various ground support facilities. As a crucial node serving civil aviation passengers, airport carbon emissions constitute an important part of the total carbon emissions throughout the civil aviation operation process.

The Airport Carbon Emission Reporting Tool (ACERT) developed by the Airport Council International (ACI) can be used to identify, quantify, and manage greenhouse gas emissions from airports worldwide. ACERT categorizes airport carbon emissions into three parts[135], as shown in Table 20.

Table 20 Three Major Components of Airport Activities

Major Parts	Description	Example
Part 1	Emission sources (fossil and others) owned or leased by airport operators()	Vehicle and machinery fuel, boiler room, furnace, emergency generator, fire fighting, surface deicing, maintenance.
Part 2	Electricity, heat or steam emissions purchased and used by the airport operator	Electricity and heat from urban utilities.
Part 3	Airport system resources owned by non-airport operators	Aircraft (engine, auxiliary power unit APU), engine testing, deicing, landside traffic, employee business travel, third party emissions (e.g. boilers, refrigeration, generators, buildings).

The Study on Carbon Emission Reduction Surveys and Countermeasures for Chinese Airports indicates that the carbon emissions from the third part of airport activities in Table 20 account for 84%-92% of the total airport carbon emissions, followed by the second part, which accounts for approximately 7%-17%, while the first part only accounts for 0.5%-2%. Together, the first and second parts constitute 7.5%-19% of the total emissions. The third part includes carbon emissions from aircraft engines during the landing and take-off (LTO) phase at airports, which contributes to the relatively high carbon emissions in this part to some extent.

In 2014, the China Civil Aviation Association conducted a survey on carbon emissions from over 40 Chinese airports. The report conducted statistical

[135] Airport Council International. ACERT Version6.0 User Manual [R]. Montreal: Airport Council International, 2021.

analysis on 16 airports with complete data and found that the carbon dioxide emissions of airports increased with the increase in passenger throughput, following a consistent trend with the increase in throughput. There is a positive correlation between airport carbon emissions and airport passenger throughput[136]. Table 21 estimates the total carbon emissions and passenger throughput of airports of different sizes in China in 2019 based on the findings of the China Civil Aviation Association's research on passenger throughput and airport carbon emissions[137].

Table 21 Total Passenger Throughput and Carbon Emissions of Airports of Different Sizes in China in 2019

Passenger throughput scale	Number of airports (number)	Passenger throughput capacity (ten thousand person-times)	Total carbon emission (10,000 tons)	Carbon emissions per passenger (kg/ person-times)
More than 10 million person-time	39	112,631	2,742.6	24.4
1 to 10 million person-time	67	17,806	476.3	26.7
Less than 1 million person-time	132	4,726	163.7	34.6

As can be seen from Table 21, larger airports have lower carbon emissions per passenger, mainly due to their higher passenger density, which allows for a more effective distribution of fixed airport carbon emissions. In 2019, 39 airports in China with passenger throughput exceeding 10 million handled 83% of domestic passenger throughput, while the smaller 199 airports only handled 17%. Most of the airports to be built in China in the future will be smaller regional airports, which do not have a strong scale effect for carbon reduction and require further exploration of carbon reduction methods for airports.

Overall, aircraft emissions during landing and take-off (LTO) phase account for

136 China Airports Association. Research on Carbon Emission Reduction Survey and Mitigation Strategies of Chinese Airports [R]. China Airports Association, 2014.

137 The data on the number of airports and passenger throughput is sourced from the "2019 Civil Aviation Airport Production Statistics Bulletin".

approximately 80%-90% of airport carbon emissions[138]. Based on an average passenger travel distance of 1,774 km in 2019, the carbon emissions per passenger kilometer of airport turnover are 27.5-39.0 gCO_2/passenger-km. Among these, the carbon emissions per passenger kilometer of airport non-aircraft emission sources excluding the LTO phase are 2.8-7.4 gCO_2/passenger-km, accounting for 2.5%-7.5% of the total carbon emissions throughout the entire civil aviation passenger transport process.

30. How to Achieve Structural Optimization in the Passenger Transport Industry under the "Dual Carbon" Strategy?

The substitution of high-speed rail for medium and short-distance transportation in civil aviation is strong. Currently, some regions lag in high-speed rail development, and the attractiveness of the passenger transport market for some high-speed rail lines needs to be improved, indicating room for optimizing the passenger transport structure. It is necessary to vigorously promote supply-side reforms in high-speed rail and civil aviation, leveraging the low-carbon advantages of high-speed rail. Meanwhile, actively introducing and reforming energy-saving and emission-reduction technologies will help achieve the "dual carbon" strategic goals while better serving passenger travel.

(1) Leveraging the advantages of railways and civil aviation to improve the utilization of existing facilities

In western China, high-speed rail, conventional rail lines, and some regional airport routes have issues of low-capacity utilization. Since a significant number of emissions are generated from infrastructure such as stations and lines during daily operations, improving the utilization rate of existing facilities and equipment is a crucial way to reduce carbon emissions.

Given the relatively low level of economic development in western China, it is necessary to assess passenger transport demand in the region and fully leverage the convenience and economic advantages of high-speed rail for medium and short distances. By lowering the service focus of high-speed rail and civil aviation, increasing the number of stopovers for medium and short-distance trains on high-speed rail in underdeveloped areas, improving high-speed rail accessibility, and attracting more road passengers with high carbon emissions, a wider range of passengers can be served.

[138] ZHU Jialin, HU Rong, ZHANG Junfeng, et al. Research on the Measurement and Evolution Characteristics of Aircraft Carbon Emissions in China [J]. *Journal of Wuhan University of Technology (Transportation Science & Engineering)*, 2020, 44(03): 558-563.

The "Several Opinions of the State Council on Promoting the Development of the Civil Aviation Industry" proposes strengthening the connection between trunk and regional lines, as well as between regional lines themselves, to improve the accessibility and utilization of small and medium-sized airports. In areas not yet covered by high-speed rail, it strengthens the connections between regional airports and between regional airports and hub airports, with railway (including high-speed rail) transportation serving as the primary means for medium and short-distance travel and civil aviation as a supplement.

(2) Improving transportation connections around high-speed rail stations and airports to enhance market coverage of high-speed rail and civil aviation services

Western China is vast and sparsely populated, so it is necessary to accelerate the establishment of a medium and long-distance passenger transport service system centered on "air-rail combined transportation." The cost of railway construction in western China is high, and high-speed rail coverage in some areas will be difficult to achieve in the short term, so regional airports should be relied on to provide external long-distance travel services.

Currently, regional airports and high-speed rail stations in underdeveloped areas have poor connecting conditions with surrounding areas, leading to high transfer times and costs for passengers. Some high-speed rail stations and airports have fewer service flights, prompting many passengers to choose taxis or self-driving as transfer options, indirectly hindering the operational development of connecting transportation. Improving transfer conditions, establishing integrated transportation services, and reducing the overall time and cost of passenger travel can effectively encourage passengers to choose high-speed rail and civil aviation, thus improving the utilization rate of existing facilities and expanding the reach of high-speed rail and civil aviation services.

Multilevel public transportation networks should be provided around high-speed rail stations and regional airports, actively introducing dedicated bus lines, long-distance buses, and rapid transit systems to gradually form transportation hubs. At stations where passenger flow conditions and transfers are not yet mature, fixed-point and fixed-route shuttle buses should be operated to connect with urban core attractions, providing flexible route connection services and achieving seamless connections between "high-speed rail (civil aviation) and buses," thereby benefiting residents of a wider range of counties and cities with high-speed rail and airport services.

(3) Enriching the service product system of high-speed rail and

strengthening the alignment of high-quality services with economic development levels

Since China's high-speed rail enterprises implemented market-based pricing, they have not yet provided reasonable and targeted preferential policies based on passenger flow demand and passenger types to encourage passengers to choose high-speed rail for travel. Full research should be conducted on the market-oriented reform mechanism for high-speed rail tickets to encourage people to choose this green travel mode and contribute to optimizing China's passenger transport structure.

Currently, China's high-speed rail ticket prices have little flexibility based on distance and region, making them less attractive to western residents. The "Notice on Reforming and Improving the Fare Policy for High-Speed Railway and EMU Passengers" issued in 2015 stated that discounts can be implemented based on transportation market competition, differences in service facilities, passenger flow distribution patterns, passenger affordability, and demand characteristics. High-speed rail enterprises should analyze train occupancy rates on various segments and competitive behaviors of other transportation modes, leverage the quasi-public welfare characteristics of railway transportation, implement a market-oriented flexible fare mechanism, and adopt ticketing strategies such as regional pricing and time-of-day pricing that are tailored to passenger demand and economic development levels. Preferential ticketing should be provided for the elderly, disabled, military personnel, students, and even low-income groups. This will not only benefit the transport capacity of surplus lines in the west but also promote social and economic development in the region.

(4) Accelerate technological advancements in high-speed rail and civil aviation to reduce transportation carbon emission factors

Accelerating the transition to cleaner electricity and adjusting the power generation structure can reduce the carbon emission factor of high-speed rail, thereby cutting down carbon dioxide emissions. From 2006 to 2020, the electricity sector in China reduced carbon dioxide emissions by approximately 1.853 billion tons. Among this, the contribution of non-fossil energy alternatives accounted for 62%, and the reduction in coal consumption accounted for 36%[139]. According to the "2030 Carbon Peak Action Plan" issued by the State Council, the comprehensive energy consumption per unit of transport turnover

[139] YANG Fan, ZHANG Jingjie. The Status and Prospect of Low-carbon Development of Electric Power Industry in China Under Carbon Peak and Carbon Neutrality Targets [J]. *Environmental Protection*, 2021, 49(17): 8-14.

for the national railway should decrease by 10% by 2030 compared to 2020. Based on the 2030 and 2035 power generation structure forecasts by the EIA, China's high-speed rail carbon emission factor will decrease by 31.9% and 36.8%, respectively, compared to 2019. Therefore, adjusting the power generation structure can significantly reduce the carbon emission factor in the traction and operation phase of high-speed rail.

The development of sustainable aviation fuel, the improvement of fuel efficiency for terminal products, and the enhancement of electric and intelligent airport operations are the key directions for aviation's low-carbon development. The "2030 Carbon Peak Action Plan" emphasizes the need to promote advanced bio-liquid fuels, sustainable aviation fuels, and other alternatives to traditional aviation fuels to reduce the carbon emission factor of civil aviation. With the development of third-generation biofuels using microalgae as raw materials, sustainable aviation fuels could potentially replace aviation kerosene on a significant scale after 2030[140].In the long term, strengthening the independent innovation and research of energy-efficient aviation products, actively developing low-energy-consuming engines and aircraft, and exploring the application of clean energy in civil aviation will support the realization of the aviation sector's carbon reduction development path.

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[140] QI Mengdi, KE Xiaoming, WANG Dianming. Research on the Trend of Transportation Decarbonization [J]. *Green Petroleum & Petrochemicals,* 2019, 4(02): 1-11.

From Editor

This report covers multiple sectors, including non-road mobile machinery, shipping, aviation, and passenger transport structure adjustment. It introduces the current status and development trends in each sector, analyzes the main challenges currently faced, and proposes corresponding solutions and policy recommendations. Through a detailed discussion of international and Chinese policies, market developments, electrification processes, and technological innovations, this report provides an important reference for the green and low-carbon transformation of the non-road transportation sector.

The market for non-road mobile machinery is developing rapidly worldwide, especially in the United States and the European Union, where significant progress has been made in electrification. In the U.S. market, the share of battery-powered non-road mobile machinery has been rising year by year; however, the development of hydrogen fuel cells is still in its early stages. The EU has also made significant achievements in electrification, particularly in the forklift and aerial work platform sectors. In China, significant progress has been made in promoting electrification in construction machinery and agricultural machinery, though challenges remain, such as pollution emissions and the difficulty of phasing out old machinery. Various measures, including financial subsidies, environmental information disclosure, coding registration, and the creation of high-emission machinery restricted zones, have been introduced to reduce emissions and carbon from non-road mobile machinery. However, challenges such as the difficulty of phasing out old machinery, high pollutant emissions, and insufficient technological innovation persist. Increasing financial subsidies and policy support, encouraging the phasing out of high-emission old machinery, promoting the research and application of electrification technologies, strengthening pollutant emission monitoring, and improving environmental information disclosure and coding registration systems are effective solutions to these issues.

The shipping industry is one of the major sources of global carbon emissions. Industry organizations, such as the International Maritime Organization (IMO), as well as major shipping countries and regions like the U.S., China, and the EU, have introduced a series of policies and measures to promote emission reductions and the green transformation of the shipping industry. However, the shipping industry faces challenges such as slow technological innovation, insufficient infrastructure, and difficulties in policy implementation. More efforts are needed in technological innovation and market applications to address the growing emission pressures. Strengthening international cooperation, promoting technological innovation, accelerating the construction of port shore power facilities, optimizing port operations, introducing more incentive measures to promote the widespread use of new energy equipment, and improving regulations and standards to ensure the effective implementation of policies are key to the green transformation of the shipping industry.

Aviation occupies a key position in the global transportation system, and as air travel demand continues to grow, so do carbon emissions. China's demand for air passenger and cargo transport is high, with significant growth expected in the future. To achieve emission reduction goals, the aviation industry needs to take proactive measures to improve energy efficiency and reduce carbon emissions per unit output. Both domestic and international aviation industries have set clear emission reduction targets and policies to gradually move the industry towards a low-carbon direction. Improving the energy efficiency of aircraft, promoting the use of sustainable aviation fuel, establishing strict carbon emission standards and reduction targets, encouraging technological innovation, promoting the development of electric and hydrogen fuel cell-powered aircraft, and strengthening international cooperation to jointly address aviation sector emissions are essential steps for achieving the low-carbon transformation of the aviation industry.

In terms of passenger transport structure adjustment, China's high-speed rail (HSR) and civil aviation have made significant progress in recent years, becoming the main modes of intercity transportation. In the face of the "dual carbon" strategy, the supply structure of HSR and civil aviation needs further optimization to achieve a rational division of labor for medium- and long-distance travel, enhancing the overall low-carbon efficiency of the transportation system. By adjusting the passenger transport structure rationally, carbon emissions can be effectively reduced, and transportation efficiency can be improved.

In conclusion, all levels of government should strengthen policy support and guidance for green and low-carbon transportation, set clear targets and implementation plans, and promote the transformation of the transportation industry toward zero emissions. Increased investment in research and development of electrification, hydrogen fuel cells, and other new energy technologies should be encouraged, and enterprises should be supported in technological innovation. The promotion and application of new technologies in the transportation industry should be accelerated. Enhanced cooperation and exchange with international organizations and other countries should be pursued, drawing on advanced experiences and jointly advancing the global green and low-carbon development of the transportation sector. Public awareness and participation in green and low-carbon transportation should be raised through publicity and education, advocating for green travel choices and fostering a positive atmosphere of societal engagement. At the same time, a robust environmental regulatory system for the transportation sector should be established to monitor the emissions of various transportation tools and facilities, regularly assess the effectiveness of policy implementation, and adjust policies as needed. Through these measures, the challenges faced in the process of reducing emissions and pollution in the transportation sector can be effectively addressed, helping the sector achieve its ultimate goal of zero emissions and promoting the realization of green and low-carbon development.

Note

Driving the transition to zero-emission transportation is the ultimate goal for industry, while green and low-carbon development remains a key task in the short term. This terminology is mainly used in national and local government documents and is also adopted in this report when referencing relevant documents and discussing related topics.

This report covers several non-road transportation sectors, including non-road mobile machinery, shipping, aviation, and high-speed rail, and serves as a valuable supplement to the first CCTP's comprehensive research report, the "*Blue Book on China's Zero-Emission Transformation in Transportation*." It is important to note that this report does not comprehensively address freight structure adjustments and global shipping emissions, which were covered in the first *Blue Book* published in 2022. As of now, there are no updates on this topic. Therefore, readers are advised to refer to the Blue Paper for more comprehensive background information and data support.

In this report, different countries and institutions have used various statistical standards and units in their respective studies. These differences reflect the specific statistical practices and research needs of different countries and organizations. We have made efforts to provide clear explanations and comparisons in the report to help readers accurately understand and use the data. It is recommended that readers pay attention to these differences and, when necessary, consult other reliable sources to obtain more comprehensive and accurate information.

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