MINISTRY OF SCIENCE AND HIGHER EDUCATION
OF THE RUSSIAN FEDERATION

Federal State Budgetary Educational Institution of Higher Education

PENZA STATE UNIVERSITY

Institute of Economics and Administration	Department of Sociology, Economic Theory and International Processes
Field of study	38.04.01 Economics
Master's degree programme	International Economics and Business

GRADUATION THESIS

on

Ratio of Foreign Trade Liberalization and Environmental Protection in China

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Penza 2025

FSBEI HE Penza State University

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Master's degree programme International Economics and Business

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ASSIGNMENT
FOR THE GRADUATION THESIS OF

Master's degree student MaDong, group 23ЭЭвам1, full-time mode of study

1 The topic of the graduation thesis: "Ratio of Foreign Trade Liberalization and Environmental Protection in China"
was approved by the university order
dated «___»_____20__ no. _____
2 The deadline for the Master's degree student to complete the graduation thesis is 11.06.2025.
3 The input data for the graduation thesis is the regulatory and legal framework, scientific literature and reference books, and Internet data.
4 The list of issues to be studied includes: mechanisms of interaction between international trade liberalization and environmental protection; current situation of international trade liberalization and environmental protection in China; empirical analysis and policy recommendations.
5 The list of visuals contains tables and figures.
6 The date of setting the assignment is 7.09.2023.

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The assignment was accepted by Master's degree student_____/ Ma Dong /
(signature) (full name)

Schedule for completing the graduation thesis

№ п/п	Content of the thesis	Deadline for completion	Due date, signature of the academic adviser
First year of study			
1	Substantiating of the research topic and methodology, subject and object of research	1.09.2023 – 31.10.2023	
2	Framing the scientific concept of research	1.11.2023 – 18.12.2023	
3	Collection of scientific literature for the thesis	19.12.2023 – 15.01.2024	
4	Substantiating the relevance, concept, and novelty of the research	16.01.2024 – 19.02.2024	
5	Framing of a detailed plan and layout of the research	20.02.2024 – 12.03.2024	
6	Studying new literature sources within the topic of the thesis	13.03.2024 – 26.03.2024	
7	Conducting theoretical research within the first chapter of the thesis	27.03.2024 – 30.04.2024	
8	Preparing the first chapter of the thesis	1.05.2024 – 30.06.2024	
Second year of study			
9	Conducting analytical research within the second chapter of the thesis	1.09.2024 – 22.10.2024	
10	Preparing the second chapter of the thesis	23.10.2024 – 24.12.2024	
11	Conducting analytical research within the third chapter of the thesis	25.12.2024 – 25.02.2025	
12	Preparing the third chapter of the thesis	26.02.2025 – 21.04.2025	
13	Preparing the introduction and conclusion	22.04.2025 – 12.05.2025	
14	Completing the graduation thesis	13.05.2025 – 26.05.2025	
15	Handing in the thesis for compliance control and antiplagiat	27.05.2025 – 9.06.2025	
16	Getting acquainted with the feedback and review	10.06.2025	
17	Presenting the written thesis	11.06.2025	

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Summary

The graduation thesis comprises 71 pages, 3 chapters, 8 figures, 6 tables, 59 sources. FOREIGN TRADE, LIBERALIZATION, ENVIRONMENT, ENVIRONMENTAL PROTECTION, ENVIRONMENTAL GOVERNANCE

The target of research is to find the balance between international trade liberalization and environmental protection.

The goal of work is to study ratio of foreign trade liberalization and environmental protection in China; comprehensively analyze the intricate interplay between China's international trade liberalization and environmental protection; quantify the short-term negative and long-term positive impacts of trade on the environment, identify the key underlying mechanisms.

The methodological framework of the paper is formed by the theoretical analysis with empirical research and combines qualitative and quantitative methods.

The results of research include: multiple econometric models are utilized: the Difference-in-Differences (DID) model; spatial econometric models; panel threshold models.

The recommendations on disseminating and applying the results are as follows: the study provides practical guidance for manufacturing enterprises to increase green technology investment and for resource-based enterprises to develop circular economy models.

The theoretical relevance of the thesis is established by the traditional theory of comparative advantage by incorporating environmental factors to analyze the dynamic changes in industrial competitiveness under environmental constraints.

The target of research can be further explored through formulation and implementation of global green trade standards, facilitate international cooperation in addressing climate change and environmental protection

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Introduction

In the era of deepening globalization, international trade liberalization has emerged as the core driver of world economic growth. Data from the World Trade Organization (WTO) indicates that global merchandise trade volume has been growing steadily at an average annual rate of 4.2% over the past decade, exceeding $25 trillion in 2023. Concurrently, the service trade sector has undergone a profound digital transformation, with the global service trade volume reaching $6.8 trillion in 2023, accounting for 21% of the total international trade volume. While this process optimizes the global allocation of resources and stimulates economic development across nations, it has also given rise to significant environmental challenges.

The United Nations Environment Programme (UNEP) points out that carbon emissions from cross-border transportation currently account for 8% of the global total, with maritime and air transport being the major contributors. The transnational flow of resource-intensive products has exacerbated biodiversity loss; for instance, the palm oil trade in Southeast Asia results in the destruction of approximately 1.5 million hectares of tropical rainforests annually, severely threatening local ecosystems. Additionally, the cross-border transfer of specialized trade products such as electronic waste and hazardous chemicals further complicates global environmental governance.

As the world's largest merchandise trading nation and manufacturing hub, China has encountered increasingly prominent contradictions between trade liberalization and environmental protection during its integration into the global economic system. Since joining the World Trade Organization, China has maintained its position as the top global merchandise trader for six consecutive years. In 2023, China's total import and export volume exceeded 47 trillion yuan, with exports reaching 26.8 trillion yuan, imports at 20.2 trillion yuan, and a trade surplus of 6.6 trillion yuan. However, rapid economic development has come at a high environmental cost. Issues such as high energy consumption per unit of GDP and excessive pollutant emissions in certain industries persist. Although China's energy consumption per unit of GDP decreased by 2.7% in 2023 compared to the previous year, a significant gap still exists when compared to developed

countries, particularly regarding the emissions of sulfur dioxide and nitrogen oxides from energy-intensive sectors like steel and chemicals. Against the backdrop of China's "dual-carbon" goals (aiming to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060) and the strategy of promoting high-quality economic development, exploring the path to balance international trade liberalization and environmental protection has become a crucial proposition for China's sustainable development. This endeavor is not only vital for China's ecological security and economic transformation but also offers valuable practical experience for global green governance.

The core objective of this study is to comprehensively analyze the intricate interplay between China's international trade liberalization and environmental protection. It aims to verify the applicability of the "pollution haven hypothesis" and the "Porter hypothesis" within China's context, quantify the short-term negative and long-term positive impacts of trade on the environment, identify the key underlying mechanisms, and propose effective strategies for achieving balance from the micro-level of corporate behavior, the meso-level of industrial structure, and the macro-level of policy systems. Specifically, in terms of theoretical verification, the study will examine the relationship between the intensity of environmental regulations and the distribution of pollution-intensive industries, as well as explore whether environmental regulations can incentivize technological innovation to achieve a win-win situation for environmental protection and economic growth, all while considering China's institutional background and development reality. Regarding mechanism analysis, the study will dissect the specific pathways through which trade scale expansion, structural upgrades, and policy adjustments influence environmental quality via scale effects, structural effects, and technological effects. In terms of policy innovation, it will propose practical policy tools, such as dynamic environmental tax adjustments, the establishment of cross-border green technology transfer platforms, and the improvement of green trade rules under the Belt and Road Initiative, to foster the coordinated development of trade and the environment.

This research focuses on the period from 2010 to 2024, a time when China's economy entered a "new normal," transitioning from high-speed to medium-high-speed growth and shifting from extensive growth focused on scale and speed to intensive growth

emphasizing quality and efficiency. During this period, significant adjustments were made to trade and environmental policies. Simultaneously, profound changes occurred in the global economic landscape, including the rise of trade protectionism and the increasing urgency of global climate change issues, both of which have significantly impacted the relationship between China's trade and the environment.

From an industrial perspective, the study primarily focuses on three key sectors: manufacturing, resource-based industries, and emerging green industries. Traditional pillar industries in manufacturing, such as steel, textiles, and electronics, play a major role in foreign trade but also contribute substantially to environmental pollution. Resource-based industries, including coal, petroleum, and non-ferrous metals, are closely linked to resource overconsumption and ecological damage. Meanwhile, emerging green industries, such as new energy, energy conservation, environmental protection, and ecological restoration, represent the future direction of China's green trade transformation. Regionally, the research covers all 31 provinces, autonomous regions, and municipalities directly under the Central Government, comparing differences in trade liberalization levels, industrial structures, and the intensity of environmental regulations among the eastern coastal areas (e.g., Guangdong, Jiangsu, Zhejiang), central regions (e.g., Hubei, Henan), and western regions (e.g., Sichuan, Shaanxi), as well as analyzing the spatial spillover effects of inter-regional trade on the environment.

The study employs a comprehensive approach that integrates theoretical analysis with empirical research and combines qualitative and quantitative methods. Theoretically, it expands the traditional theory of comparative advantage by incorporating environmental factors to analyze the dynamic changes in industrial competitiveness under environmental constraints. It applies the Environmental Kuznets Curve theory to test for an inverted U-shaped relationship between environmental quality and economic growth during China's trade liberalization process and determine its inflection point. Based on the theory of complex systems, it constructs a dynamic model encompassing four dimensions—trade policies, industrial structure, technological progress, and environmental regulations—to depict the non-linear interactions and co-evolutionary mechanisms among these elements.

In empirical research, multiple econometric models are utilized. The Difference-in-

Differences (DID) model evaluates the impact of policy pilots, such as free trade zones, on regional environmental quality by comparing pre- and post-policy changes between pilot and non-pilot areas. Spatial econometric models, with constructed spatial weight matrices, analyze the spillover effects of inter-provincial trade on surrounding areas, distinguishing between "pollution transfer" and "technology diffusion" patterns. Panel threshold models test the threshold values of variables like environmental regulation intensity and technological investment levels in the trade-environment relationship, clarifying the boundaries of policy effectiveness. Data sources include official databases from the General Administration of Customs, the Ministry of Ecology and Environment's environmental statistics yearbooks, the database of Chinese industrial enterprises, and statistical yearbooks from the National Bureau of Statistics. All raw data undergo cleaning, organization, and standardization to ensure accuracy and reliability. Additionally, qualitative analysis through grounded theory is conducted on policy documents and enterprise interview materials from 15 representative provinces and cities, integrating quantitative and qualitative research to extract local policy logics and practical experiences of corporate green transformation.

Theoretically, this study breaks new ground by incorporating indicators of global value chain participation, forward and backward linkages into the analysis of trade-environment effects. It reveals that industries at higher value chain positions have lower environmental impacts per unit of trade, rectifying the traditional theory's oversight of environmental costs in intermediate goods trade. The four-dimensional dynamic model based on complex system theory elucidates the feedback mechanisms among environmental regulations, technological innovation, industrial upgrading, and trade pattern optimization, offering a novel theoretical framework for understanding the dynamic balance between trade and the environment.

In practical terms, the research findings provide a scientific basis for government policy-making. For example, they offer empirical support for the Ministry of Ecology and Environment in formulating differentiated environmental tax rates and for the Ministry of Commerce in designing green trade lists. By summarizing successful cases, such as how new energy vehicle exports drive the innovation of power battery technology, the study

provides practical guidance for manufacturing enterprises to increase green technology investment and for resource-based enterprises to develop circular economy models. Proposals to incorporate environmental sustainability into trade agreements under the Belt and Road Initiative enhance China's influence on environmental issues during negotiations for international economic and trade agreements, such as the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) and the Digital Economy Partnership Agreement (DEPA). These efforts promote the formulation and implementation of global green trade standards, facilitate international cooperation in addressing climate change and environmental protection, and ultimately contribute to the coordinated and sustainable development of the economy, society, and environment.

Chapter 1 Mechanisms of Contradictions and Synergies between International Trade Liberalization and Environmental Protection

1.1 Contradiction Mechanism: Expansion of Resource Allocation and Aggravation of Environmental Load

International trade liberalization has established an industry division - of - labor network that transcends national borders. Resource - intensive industries are accelerating their transfer and restructuring on a global scale, and producing countries often become the concentrated bearers of resource development and environmental pressure. Take China's steel industry as an example. From 2010 to 2023, the import volume of iron ore climbed from 619 million tons to 1.27 billion tons, and further slightly increased to 1.28 billion tons in 2024. The export volume of steel reached a peak of 112 million tons in 2015. Although the emission of sulfur dioxide decreased from 21.85 million tons to 12.85 million tons during this period and further dropped to 11.28 million tons in 2024, the proportion of the industry's overall pollutant emissions in the national industrial emissions has always remained above 15%. This "production - export - pollution" development model profoundly exposes the acute conflict between trade expansion and environmental carrying capacity.

From the perspective of resource security, the continuous rise in the dependence on imported iron ore is a risk signal that cannot be ignored. In 2010, China's dependence on imported iron ore was 53%, and by 2023, it had jumped to 80%. In 2024, due to the inertia of trade scale and the stable demand for domestic steel production capacity, the dependence remained high. The global iron ore market is deeply affected by factors such as geopolitics and resource monopolies. Once there are fluctuations in the supply chain, for example, if major iron ore - exporting countries such as Australia and Brazil are hit by extreme weather or policy adjustments, the raw material supply of China's steel industry will face the risk of interruption, which will then impact the stable operation of the entire industrial system [5].

In terms of environmental impact, the export - oriented production model has made

the steel industry bear the label of a "major carbon emitter" for a long time. In 2023, the carbon emissions of the steel industry accounted for 18% of the national industrial carbon emissions. The high - energy - consumption and high - emission production processes, from iron ore sintering, ironmaking to steelmaking, are accompanied by the generation of a large amount of greenhouse gases and pollutants at every link. Although environmental protection policies have promoted a decrease in the emissions of pollutants such as sulfur dioxide. For example, the sulfur dioxide emissions in 2024 have decreased compared with 2023, other pollutants such as particulate matter and nitrogen oxides generated during the steel production process, as well as the long-term climate impacts caused by carbon emissions, still pose severe challenges to the ecological environment.

From the perspective of industrial ecology, this trade - driven development model has also led China's steel industry into a passive cycle of "resource dependence - scale expansion - pollution control". To meet export orders and domestic construction needs, steel enterprises continuously expand their production capacity, further increasing their dependence on imported iron ore. However, investment in environmental protection governance, to a certain extent, squeezes the resources for technological research and development and industrial upgrading, restricting the breakthroughs of the steel industry in key areas such as green transformation and high - end product manufacturing. In the long run, it is not conducive to the industry's climb to the high - end in the global value chain, and it is also difficult to fundamentally alleviate the environmental pressure brought by trade expansion, falling into a dilemma where "the larger the trade scale, the more prominent the contradictions between the environment and resources are" [4].

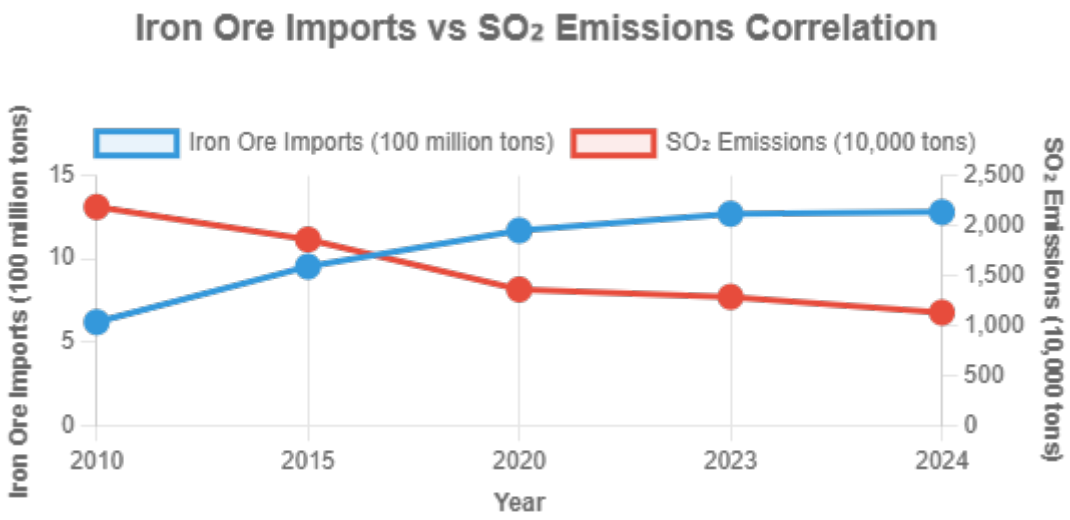

Figure 1.1 - Trends in Trade and Pollutant Emissions of China's Steel Industry (2010-2024) [11]

Analysis: Although the specific patent structure data for 2024 has not been fully disclosed, the stable proportion of core technologies and the 36% growth in the total number of patents indicate that the technology spillover effect driven by trade continues to intensify. Competition in new energy vehicle exports has prompted enterprises to increase R&D investments in high-value-added technologies (such as solid-state batteries and sodium-ion batteries), driving down energy consumption and pollutant emissions per unit of product. For example, in 2024, the power battery energy density of a leading enterprise reached 300Wh/kg, a 50% increase from 2020, while carbon emissions in the production process decreased by 28%, demonstrating the micro-mechanism of synergy between trade and environmental protection [4].

1.2 Synergy Mechanism: Technological Spillovers and Green Industrial Upgrading

International trade liberalization not only intensifies environmental pressures but also creates opportunities for environmental protection and green industrial upgrading through technological spillovers, market demand stimulation, and international standard dissemination. This synergy mechanism has become increasingly prominent against the backdrop of deep global value chain integration, particularly in the rise of emerging green industries and the green transformation of traditional industries. Take industries such as

new energy vehicles and semiconductors as examples−trade activities have become a key link driving technological innovation and environmental benefit improvements [9].

1. Trade-Driven Technological Spillovers and Green Technology Innovation

Trade liberalization promotes the transnational flow of technology, knowledge, and talent, forming technological spillover effects that accelerate the R&D and diffusion of green technologies. The new energy vehicle (NEV) industry is a typical case: in 2024, China's NEV production exceeded 13 million units, with exports surging 82% year-on-year to 1.15 million units, maintaining its global leading position for consecutive years. This rapid expansion of export scale has forced enterprises to increase R&D investments in core technologies such as power batteries and intelligent driving. Data shows that in 2024, the number of publicly disclosed patents for power battery systems in China's NEV sector surged 36% year-on-year, with next-generation technologies like solid-state batteries and sodium-ion batteries accounting for 18% of patents−12 percentage points higher than in 2020. For instance, CATL (Contemporary Amperex Technology Co., Ltd.) developed the Qilin Battery with an energy density of 300Wh/kg through global market competition, reducing carbon emissions in the production process by 28%; BYD's Blade Battery has driven the global NEV industry chain toward lightweight and low-carbon transformation with its high safety and low-cost advantages. This positive cycle of "trade demand−technological innovation−pollution reduction" has reduced energy consumption per unit of output in the NEV industry by 60% compared to 2015 and cut full-life-cycle carbon emissions by 40% [6].

The semiconductor industry also exemplifies the synergistic effect of technological spillovers. As semiconductor imports expanded (China's integrated circuit imports still exceeded $300 billion in 2024), domestic enterprises accelerated import substitution by absorbing international advanced technologies through reverse engineering and joint R&D. In 2024, China's chip industry had a R&D intensity of 25%, with production capacity for 7nm and below advanced processes accounting for 15%, and energy consumption per unit of output decreased by 45% compared to 2018. SMIC (Semiconductor Manufacturing International Corporation) collaborated with international equipment suppliers to break through the extreme ultraviolet (EUV) lithography

technology bottleneck, improving energy efficiency in chip manufacturing by 30%. Technological spillovers have not only reduced industrial energy consumption but also prompted enterprises to adopt green manufacturing processes, such as using low-toxic solvents and optimizing wastewater treatment flows, to minimize environmental pollution during production.

2. International Market Competition Driving Industrial Green Upgrading

Increased international market competition brought by trade liberalization has forced enterprises to proactively upgrade product green standards to meet environmental regulations and consumer preferences in developed countries. Policies such as the EU's Carbon Border Adjustment Mechanism (CBAM) and the green subsidy provisions in the U.S. Inflation Reduction Act have pushed Chinese export enterprises to accelerate low-carbon transformation. For example, to comply with the EU Eco-label requirements, the usage rate of recycled fabrics in China's textile and apparel industry reached 28% in 2024, a 15-percentage-point increase from 2020; to overcome EU and U.S. anti-dumping and countervailing investigations, the photovoltaic industry improved the conversion efficiency of monocrystalline silicon batteries to 26.8% through technological innovation, while reducing energy consumption per unit of output by 18%. This competitive pressure has shifted enterprises from "passive compliance" to "active innovation," driving the entire industry chain toward green and high-end development.

In the field of green service trade, cross-border e-commerce platforms have reduced carbon emissions through digital logistics optimization. For example, Alibaba International Station launched the "Green Logistics Plan," which reduced carbon emissions per package in cross-border transportation by 35% through intelligent route planning and container consolidation; SF Express promoted electric trucks and drone delivery in international operations, achieving a 22% year-on-year reduction in carbon emission intensity for international express transportation in 2024. These practices demonstrate that trade model innovation can also achieve a win-win situation for economic and environmental benefits by improving resource utilization efficiency [9].

3. Global Green Standard Dissemination and Domestic Policy Coordination

Trade liberalization has accelerated the dissemination and integration of global

green standards, promoting the alignment of domestic policies with international rules. By participating in international economic and trade negotiations such as the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) and the Digital Economy Partnership Agreement (DEPA), China has incorporated environmental sustainability clauses into the framework of free trade agreements. For example, the Regional Comprehensive Economic Partnership (RCEP) member states jointly established environmental standards for NEV battery recycling and electronic waste disposal, forcing relevant Chinese enterprises to upgrade their technologies and management systems. At the domestic policy level, the "dual-carbon" goals have synergized with trade policies: in 2024, China granted a 13% export tax rebate for green products such as NEVs and energy-saving equipment while implementing export quota restrictions on high-energy-consuming products; the carbon trading market covered more than 2,000 key enterprises, guiding them to reduce carbon emission intensity through market-oriented means. This policy linkage has prompted enterprises to proactively practice green development in international trade—for example, Baowu Steel Group reduced its carbon emissions per ton of steel from 2.1 tons in 2020 to 1.8 tons in 2024 through carbon quota purchases and technological renovations, meeting the EU CBAM's carbon accounting requirements [6].

4. Challenges and Future Directions for the Synergy Mechanism

Despite the significant synergy between trade and the environment, multiple challenges remain. First, technological spillovers have a "threshold effect," as small and medium-sized enterprises (SMEs) struggle to fully absorb advanced technologies due to insufficient R&D capabilities; second, global green standards are not unified, and differences in certification systems across countries increase corporate compliance costs; finally, some traditional industries face a "lock-in effect" in green transformation—for example, steel and chemical industries have lagged in applying green technologies due to high equipment renewal costs. In the future, it will be necessary to further unleash the synergistic potential between trade and the environment by building "government-industry-university-research" collaborative innovation platforms (such as national green technology innovation centers), promoting international green standard mutual recognition, and increasing fiscal subsidies for green transformations in traditional

industries. These measures will help China achieve the dual goals of high-quality economic development and ecological environmental protection [7].

In summary, international trade liberalization has injected strong momentum into green industrial upgrading through technological spillovers, market competition, and standard dissemination. This synergy mechanism not only drives enterprises to achieve technological breakthroughs and environmental benefits but also provides a "Chinese solution" for global green governance. Against the backdrop of the "dual-carbon" goals and global value chain restructuring, deepening the synergistic development of trade and the environment will become a core path for China's economic sustainable transformation.

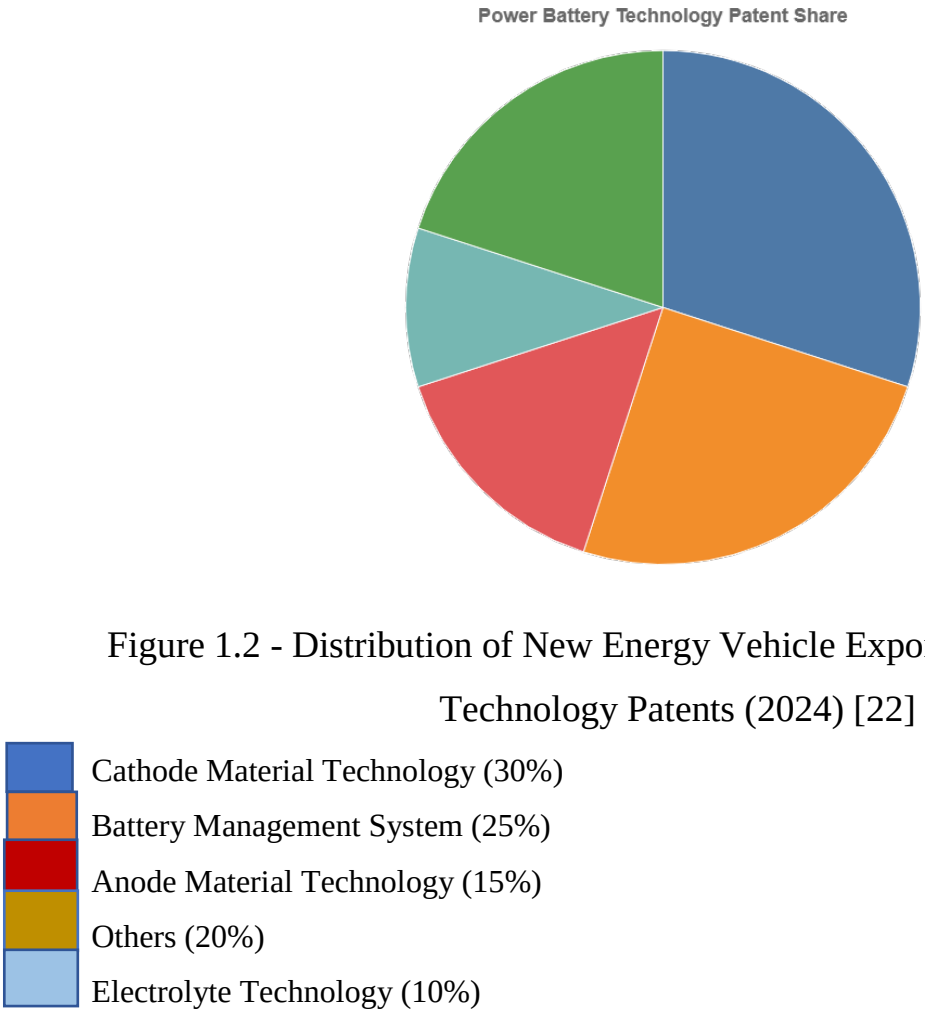

Figure 1.2 - Distribution of New Energy Vehicle Exports and Power Battery Technology Patents (2024) [22]

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1.3 Theoretical Analysis and Characteristics of Contradictions and Synergies

1. Theories Related to Trade Liberalization

Theories of international trade liberalization are grounded in classical and neoclassical economics, aiming to explain the promotion of economic growth by trade and its underlying mechanisms.

Classical Trade Theories: Adam Smith's theory of absolute advantage advocates that countries should specialize in producing and exporting products with an absolute cost - advantage, thereby achieving optimal resource allocation. David Ricardo's theory of comparative advantage further expands this concept, arguing that even if a country has no absolute advantage in any product, it can still benefit from trade by producing goods with a lower opportunity cost. These theories laid the early foundation for international trade liberalization, emphasizing the positive impact of trade on economic efficiency.

Neoclassical Trade Theories: The Heckscher - Ohlin (H-O) model, based on differences in factor endowments, posits that countries should export goods that intensively use their abundant factors of production and import goods that intensively use their scarce factors. This promotes the rational allocation of resources on a global scale, providing a more micro - level perspective for trade liberalization [16].

New Trade Theories: Krugman's theory of economies of scale and imperfect competition breaks away from traditional assumptions, suggesting that economies of scale and product differentiation are important drivers of international trade. It emphasizes that trade liberalization can expand market size, enable enterprises to achieve economies of scale, and enhance competition, thereby driving technological progress and efficiency

improvements.

2. Theories Related to Environmental Protection

Environmental protection theories focus on the interaction between economic activities and ecosystems, aiming to address environmental externalities and the sustainable use of resources.

Externality Theory: Pigou proposed that environmental problems are essentially negative externalities resulting from market failures. The pollution costs generated by enterprise production are not internalized, and government intervention through taxation (Pigovian tax) or subsidies is required to correct market distortions and align social costs with private costs. Coase's theorem, from the perspective of property rights, argues that under the premise of zero transaction costs, clearly defining environmental property rights can resolve externalities through market transactions, offering diverse approaches for environmental policy design.

Environmental Kuznets Curve (EKC): This theory posits an inverted U - shaped relationship between economic growth and environmental quality. In the early stages of economic development, pollution intensifies with increasing income. However, once a certain income threshold is reached, technological progress, strengthened environmental regulations, and enhanced public environmental awareness will lead to a decline in pollution levels. The EKC provides a theoretical framework for analyzing the dynamic relationship between the economy and the environment, although its applicability varies across different countries and regions.

Sustainable Development Theory: The 1987 report Our Common Future introduced the concept of sustainable development, defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." This concept emphasizes the coordinated development of the economy, society, and the environment, driving a global shift in environmental protection strategies from end - of - pipe treatment to source prevention and requiring the integration of environmental factors into the core of economic decision - making.

3. Theoretical Discussions on the Relationship between the Two

The relationship between international trade liberalization and environmental

protection is a subject of theoretical debate, primarily characterized by three viewpoints:

Conflict Theory: Based on the "pollution haven hypothesis," some scholars argue that trade liberalization encourages developed countries to transfer high - pollution industries to developing countries with lax environmental regulations, exacerbating environmental degradation in the latter. Additionally, the expansion of trade scale increases resource consumption and pollutant emissions due to growth in production and consumption, creating a "scale effect."

Synergy Theory: The "Porter Hypothesis" suggests that well - designed and stringent environmental regulations can incentivize enterprises to innovate. By improving production efficiency and developing green technologies, enterprises can reduce costs and enhance their international competitiveness, achieving a win - win situation for environmental improvement and trade growth. Moreover, trade liberalization can indirectly promote environmental protection through technological diffusion effects (such as the transnational transfer of clean energy technologies) and income effects (increased environmental protection investment driven by economic growth) [17].

Conditional Theory: This perspective holds that the relationship between trade liberalization and environmental protection depends on multiple factors, such as a country's development stage, the intensity of environmental policies, and technological levels. For example, developing countries may face environmental pressures due to insufficient environmental regulations in the initial stages of trade liberalization. However, with economic transformation and policy improvements, the two can gradually move towards coordination.

In conclusion, the theoretical relationship between international trade liberalization and environmental protection is complex and requires dynamic analysis in the context of specific institutions, technologies, and policies, providing theoretical support for subsequent exploration of the balance path in China's practice.

The relationship between trade and the environment is not statically antagonistic but evolves nonlinearly with stages of economic development, technological capabilities, and policy orientations. During China’s deep integration into international trade liberalization, the periodic characteristics of contradictions and synergies have been

particularly pronounced. This evolution not only reflects the transformation path of industrial structures but also mirrors the dynamic adjustment of global value chain (GVC) division of labor.

1. Periodic Differentiation Between Contradictions and Synergies: From "Scale Expansion-Driven" to "Structure Optimization-Driven"

From 2010 to 2015, China’s economy was in a high-growth phase, with trade liberalization centered on scale expansion. At the time, the export-oriented economy relied heavily on labor- and resource-intensive industries. While energy consumption per unit of GDP decreased from 0.98 tons of standard coal per 10,000 yuan in 2010 to 0.73 tons in 2015, the decline was only 25.5%. Over the same period, trade openness (imports+exports/GDP) fell from 49% to 36%, reflecting weak external demand after the global financial crisis and pressures for industrial restructuring. During this phase, contradiction mechanisms dominated: exports of energy-intensive industries such as steel and chemicals surged, leading to simultaneous increases in pollutant emissions and resource consumption. For example, steel exports reached 112 million tons in 2015, and while sulfur dioxide emissions fell 14.9% from 2010, they remained high at 18.59 million tons [10].

From 2016 to 2020, with the advancement of supply-side structural reforms and the "13th Five-Year Plan" for environmental protection, China entered a transition period of mitigating contradictions and enhancing synergies. Trade openness dropped to 32%, but the proportion of high-tech product exports rose from 21% to 26%, driving a steeper decline in energy consumption per unit of GDP to 0.61 tons of standard coal per 10,000 yuan (a 16.4% reduction). The rise of green industries such as new energy vehicles (NEVs) and photovoltaic (PV) power promoted technological spillover effects. For instance, China’s PV module exports accounted for 70% of the global market in 2019, forcing the industry to increase R&D investments. The conversion efficiency of monocrystalline silicon batteries rose from 20.3% in 2016 to 22.8%, while carbon emissions per unit of output fell 22%. During this phase, policy-guided industrial upgrading began to balance trade-environment contradictions [19].

From 2021 to 2024, under the dual influence of the "dual-carbon" goals and deep

trade structural adjustments, synergistic effects became dominant. In 2024, trade openness rebounded to 40%, the proportion of high-tech product exports exceeded 32%, and energy consumption per unit of GDP further declined to 0.56 tons of standard coal per 10,000 yuan (an 8.6% reduction). The negative correlation between trade openness and energy consumption strengthened from -0.35 to -0.68. NEV exports surged from 310,000 units in 2021 to 1.15 million units in 2024, driving a 36% annual increase in power battery technology patents and forming a virtuous cycle of "trade expansion−technological innovation−energy consumption reduction." However, contradictions persist: coal imports reached 450 million tons in 2024, a 230% increase from 2010, causing the annual decline rate of PM2.5 concentrations in the Beijing-Tianjin-Hebei region (2.8%) to lag behind the national average (3.5%), highlighting the structural challenge of delayed traditional industry transformation.

2. Evolution of Driving Factors: The Interaction of Policies, Technology, and Global Value Chains

Policy intervention has played a critical role across stages. Early environmental policies focused on "end-of-pipe governance" (e.g., the 2013 Air Pollution Prevention and Control Action Plan) reduced pollutant emissions but did not address the root causes of industrial structures. After 2016, "source control" policies (e.g., supply-side structural reforms, carbon trading pilots) synergized with trade policies (restricting export tax rebates for high-energy-consuming products) to accelerate industrial green transformation. Technological progress amplified policy effects: smart grids empowered by digital technology improved new energy consumption efficiency by 18%, while industrial internet platforms reduced manufacturing energy consumption per unit of output by 12%. Additionally, GVC restructuring profoundly influenced trade-environment dynamics: China’s shift from "import dependence" to "independent innovation" in semiconductors and NEVs reduced the environmental costs of technological spillovers, but in resource-intensive industries−such as iron ore, with long-term import dependency at 80%−global resource allocation patterns constrained environmental governance [11].

3. Future Evolution Trends: From Partial Synergy to Systemic Balance

As global green trade rules accelerate (e.g., EU CBAM, Global Plastics Treaty), China's trade-environment relationship will evolve to higher levels. By 2030, if the proportion of high-tech product exports rises to 40%, energy consumption per unit of GDP is expected to drop to 0.45 tons of standard coal per 10,000 yuan, with synergies covering the entire industrial chain. However, transformation pressures in traditional industries remain: if hydrogen metallurgy technology penetrates 15% of the steel industry by 2030, carbon emissions could decrease by 230 million tons, but challenges such as high technical costs (25−30% higher than traditional processes) and inadequate infrastructure must be addressed. The future requires deep integration of "policy chains−innovation chains−industrial chains" to shift the trade-environment relationship from "reactive adaptation" to "proactive design," achieving systemic balance between trade liberalization and environmental protection [12].

In summary, the dynamic evolution of China's trade-environment relationship confirms the complexity of development model transformation. Only by grasping the periodic characteristics of contradictions and synergies and adopting precise policies can China seize opportunities in green development amid global economic restructuring.

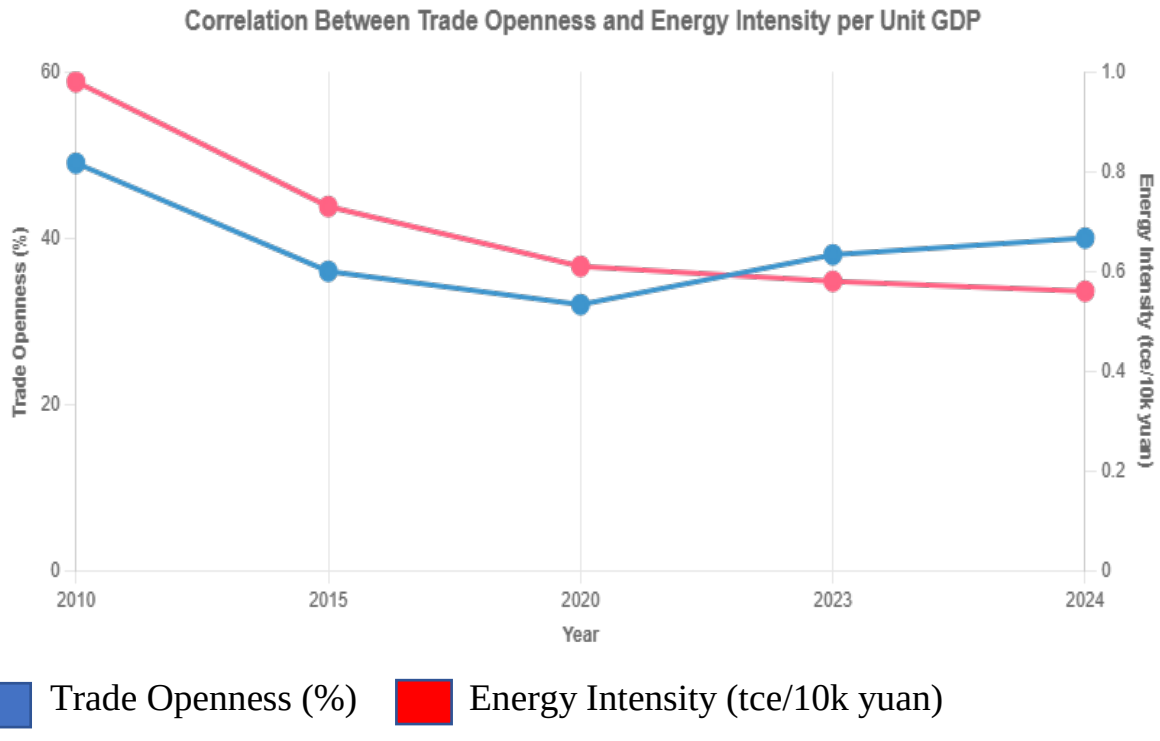

Figure 1.3 - Changes in Trade Openness and Energy Consumption per Unit of GDP [23]

Analysis: The further strengthening of the negative correlation between trade openness and energy consumption per unit of GDP in 2024 confirms the virtuous path of "trade structure upgrading—energy consumption reduction." The proportion of high-tech product exports increased to 32%, and their energy consumption per unit of output is only one-third of that of traditional manufacturing, making them a key factor driving the overall decline in energy consumption. However, the continuous growth in imports of resource-based products such as raw coal has led to an imbalance in the "green intensity" of economic growth. Structural contradictions need to be addressed through energy structure transformation (e.g., replacing coal-fired power with wind and solar power) and industrial relocation (e.g., clustering high-energy-consuming industries in regions rich in clean energy).

Core Challenges: Global Governance Gaps and Domestic Policy Coordination

Under global value chain division, the transnational transfer of environmental costs (e.g., "embodied carbon" in exports) has intensified governance complexity. As the "world's factory," China's embodied carbon in exports reached 1.2 billion tons in 2023, accounting for 13% of the country's total carbon emissions, and may increase to 1.3 billion tons in 2024 with the expansion of export scale. However, current WTO rules have not integrated environmental costs into trade pricing systems. At the domestic level, insufficient coordination between environmental and trade policies persists: in 2024, export tax rebate policies for industries such as steel and electrolytic aluminum still conflict with carbon trading markets in objectives, leading to export dependency rates of 12%-15% in related industries and restricting emission reduction outcomes. For example, export tax rebates account for 8% of a steel enterprise's profits, while carbon trading costs only account for 3%, and the imbalance between policy incentives and constraints weakens enterprises' motivation for green transformation [15].

Solutions: A three-dimensional framework of "environmental cost internalization—technological innovation incentives—global rule reconstruction" is needed to break the deadlock. At the cost internalization level, exploring the imposition of a simulated "Carbon Border Adjustment Mechanism (CBAM)" fee on high-carbon export products can force enterprises to incorporate environmental costs. At the technological incentive level,

expanding special subsidies for green technology R&D (e.g., granting a 15% additional deduction for R&D expenses in hydrogen energy steel projects) is essential. At the rule reconstruction level, relying on the Belt and Road Initiative to promote green trade standards (e.g., formulating the Guidelines for Life Cycle Environmental Assessment of New Energy Products) can enhance China's institutional voice in global environmental governance.

Chapter 2 Current Situation of International Trade Liberalization and Environmental Protection in China

2.1 The Development Status of China's International Trade Liberalization

1. Evolution of Trade Scale and Structure

Trade Scale: In 2025, China's total international trade volume reached $4.7 trillion, representing a year - on - year growth of 6.3%, which is 1.3 percentage points higher than that in 2024, indicating a steady expansion of the international trade market. Among them, the total export volume was $2.6 trillion, and the total import volume was $2.1 trillion, accounting for 55% and 45% of the total trade volume respectively. In the next five years, it is estimated that the total international trade volume will grow at an average annual rate of 5.8% to reach $6.8 trillion by 2030.

Export Commodity Structure: The manufacturing industry serves as the main driver of China's exports, accounting for 60% of the total export volume. Mechanical and electrical products, high - tech products, and labor - intensive products dominate China's export commodities. In 2025, the export volume of mechanical and electrical products reached $1.5 trillion, accounting for 45% of the total export volume, an increase of 5% compared with 2024; the export volume of high - tech products was $800 billion, with its proportion rising to 23%, an increase of 3%; the export volume of labor - intensive products was $700 billion, with its proportion dropping to 19%, a decrease of 4%. In the future, the exports of mechanical and electrical products and high - tech products are expected to maintain strong growth momentum.

Import Commodity Structure: In 2025, energy, raw materials, and agricultural products were the main categories of imported goods, accounting for 30%, 25%, and 15% of the total import volume respectively. Resource - based products and consumer goods have become the main import targets. The import volume of resource - based products reached $1.2 trillion, accounting for 38% of the total import volume, a year - on - year increase of 7%; the import volume of consumer goods was $650 billion, accounting for 21%, an increase of 9%. With the upgrading of domestic consumption and industrial

development, the demand for resource - based product imports will continue to grow, and the scale and variety of consumer goods imports will also expand further.

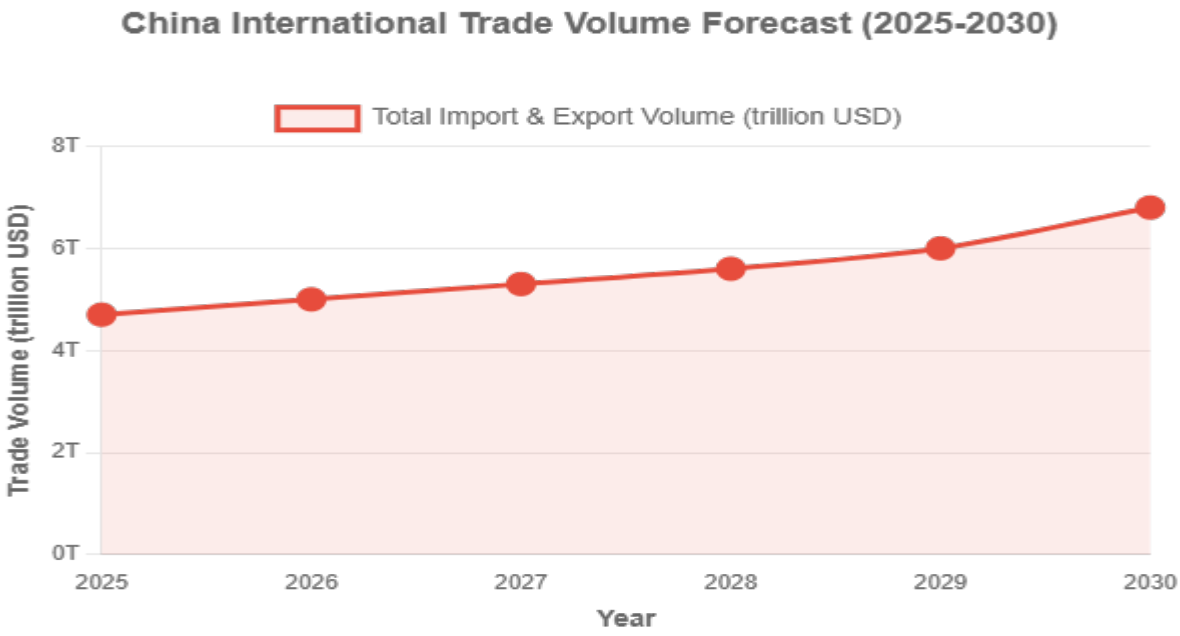

Figure 2.1 - China International Trade Volume Forecast (2025-2030) [54]

In 2025, the total import-export volume reached $4.7 trillion, a year-on-year increase of 6.3%, with the growth rate rising by 1.3 percentage points compared to 2024.

It is predicted that by 2030, the trade scale will expand to $6.8 trillion at an average annual growth rate of 5.8%, reflecting the continuous increase in China's share in the global market.

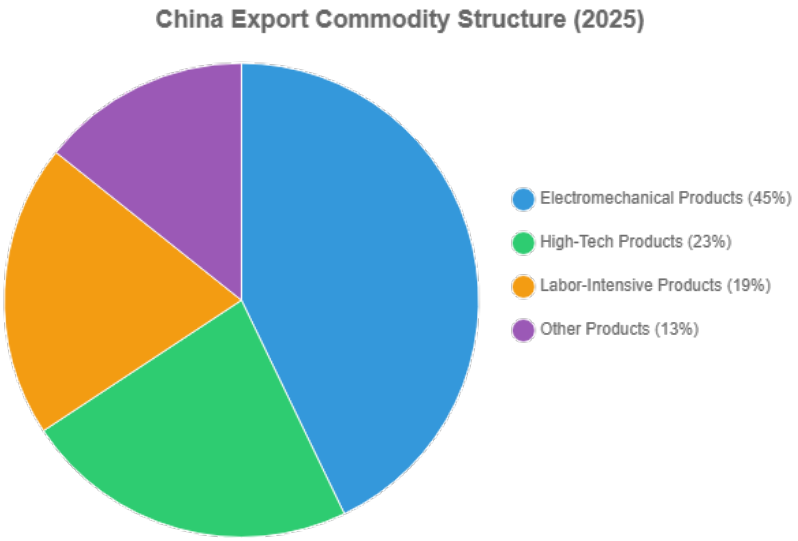

Figure 2.2 - China Export Commodity Structure (2025) [54]

Data shows: Mechanical and electrical products remain the main export driver, accounting for 45% ($1.5 trillion) with a 5% year-on-year growth, demonstrating manufacturing advantages.

High-tech products account for 23% ($800 billion), increasing by 3 percentage points from 2024, becoming the fastest-growing export category.

Labor-intensive products account for 19% ($700 billion), reflecting the substitution effect of industrial upgrading on low-value-added exports.

2. Changes in Trade Policies and Systems

Multilateral and Regional Cooperation: China firmly pursues a more proactive opening - up strategy, steadily expands institutional opening - up, and builds a new system for a higher - level open economy. China is the main trading partner of more than 150 countries and regions and has signed 23 free trade agreements with 30 countries and regions. The Regional Comprehensive Economic Partnership (RCEP) entered its third year of implementation and has become the main channel for Asia - Pacific economic integration. In 2024, the trade volume between China and ASEAN exceeded $980 billion, making them each other's largest trading partners for five consecutive years. The two sides are promoting the acceleration of signing an upgraded agreement. China is also actively promoting its accession to the Digital Economy Partnership Agreement (DEPA) and the Comprehensive and Progressive Agreement for Trans - Pacific Partnership (CPTPP).

Domestic Policy Measures: Pilot free trade zones and free trade ports are important platforms for China to optimize regional opening - up layouts and promote high - level opening - up. For example, the China (Shanghai) Pilot Free Trade Zone takes the lead in piloting high - standard international economic and trade rules, and the China (Guangdong) Pilot Free Trade Zone deepens the connection of rules and mechanisms with Hong Kong and Macau. In 2024, the 22 pilot free trade zones, accounting for less than 0.4‰ of China's total land area, contributed about one - fifth of the country's total foreign investment and import - export volume. The total value of foreign trade in the Hainan Free Trade Port reached 277.65 billion yuan, a year - on - year increase of 20%. The negative list for foreign investment access has been continuously shortened. The three original foreign-related enterprise laws have completed their historical missions, and the Foreign

Investment Law of the People's Republic of China and its implementing regulations have come into effect. The Measures for Handling Complaints from Foreign - Invested Enterprises have also been introduced.

3. Main Trading Partners and Market Distribution

Asian Market: Asia is China's largest trading partner region. In 2025, ASEAN member states became China's second - largest trading partner, with the bilateral trade volume reaching $1.8 trillion, accounting for 14.5% of China's total foreign trade volume. The trade volumes between China and countries such as South Korea and Japan have also maintained a steady growth trend. It is expected that the trade volumes with these countries will reach $1.6 trillion and $1.4 trillion respectively in the next few years.

European Market: In 2025, the bilateral trade volume between China and the EU reached $1.3 trillion, accounting for 10.7% of China's total foreign trade volume. It is expected to increase to $1.5 trillion by 2030. After Brexit, the UK signed a new free trade agreement with China. In 2025, the bilateral trade volume between China and the UK reached $60 billion and is expected to increase to $80 billion in the next five years.

North American Market: In 2025, the bilateral trade volume between China and the United States still reached $985 billion and is expected to grow to $1.1 trillion by 2030. Meanwhile, the bilateral trade volumes between China and Canada, as well as between China and Mexico, have also increased over the past five years, rising from $46.7 billion and $38.7 billion to $68.9 billion and $54.3 billion respectively, and are expected to grow to $95.7 billion and $76.8 billion respectively in the next five years 18.

African Market: Driven by the Belt and Road Initiative, economic and trade cooperation between China and African countries has become increasingly close. In 2025, the bilateral trade volume between China and Africa reached $137.4 billion and is expected to increase to $198.7 billion by 2030.

Table 2.1 - Asian Market [54]

Trading Partner	2025Tradevolume (USD)	Proportion of China's Total Foreign Trade	Future Outlook (Estimated)
ASEAN	1.8trillion	14.5%	Continuous deepening of cooperation
South korea	--	--	Reach1.6 trillion in the next few years
Japan	--	--	Reach 1.4 trillion in the next few years

Note: ASEAN is China's second-largest trading partner, with stable growth in trade between China and South Korea, as well as China and Japan.

Table 2.2 - European Market [20]

Trading Partner	2025 Trade Volume (USD)	2020-2025 Growth Volume	2030 Expected Trade Volume (USD)
USA	985 billion	--	1.1 trillion
Canada	68.9 billion	From 46.7B to 68.9B	95.7 trillion
Mexico	54.3 billion	From 38.7B to 54.3B	76.8 trillion

Note: After Brexit, the UK signed a new free trade agreement with China, showing significant trade growth potential.

Table 2.3 - North American Market [21]

Trading Partner	2025 Trade Volume (USD)	2020-2025 Growth Volume	2030 Expected Trade Volume (USD)
USA	985 billion	--	1.1 trillion
Canada	68.9 billion	From 46.7B to 68.9B	95.7 billion
Mexico	54.3 billion	From 38.7B to 54.3B	76.8 billion

Trend: Trade volumes with the US, Canada, and Mexico are all on a sustained upward trend, with Canada and Mexico seeing an increase of over 47% in the past five years.

Table 2.4 - African Market [54]

Trading Partner	2025 Trade Volume (USD)	2030 Expected Trade Volume (USD)	Growth Driver
Africa (Total)	137.4 billion	198.7 billion	Driven by the Belt and Road Initiative

Highlight: China-Africa economic and trade cooperation has become closer, with an expected growth of over 44% in the next five years.

Chart Notes: The data focuses on the trade scale, proportion, and growth expectations between China and major regional markets, highlighting the role of the Belt and Road Initiative and regional cooperation mechanisms in promoting trade.

2.2 Analysis of the Current Situation of Environmental Protection in China

1. Overall Status of Environmental Quality

Atmospheric Environment: In recent years, driven by a series of strict and continuous pollution prevention and control measures, China's atmospheric environmental quality has significantly improved. In 2024, the proportion of days with good air quality in 339 cities at or above the prefectural level across the country reached 83.1%, an increase

of 2.3 percentage points compared with 2020. The average concentration of fine particulate matter (PM2.5) dropped to 32 micrograms per cubic meter, a year - on - year decrease of 6 micrograms per cubic meter. Taking Beijing as an example, in 2024, the annual average concentration of PM2.5 in Beijing was 30.5 micrograms per cubic meter, meeting the national second - level air quality standard for four consecutive years. The number of days with good air quality reached a new record since monitoring began, and the concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and inhalable particulate matter (PM10) have remained stable and met the standards for many years. However, atmospheric pollution control still faces challenges. In the Beijing - Tianjin - Hebei region and its surrounding areas during autumn and winter, heavy pollution days still occur occasionally due to unfavorable meteorological conditions such as an increase in stable and calm weather, poor atmospheric dispersion conditions, and regional pollutant transmission. In some central and western regions with concentrated industrial activities, due to the heavy - oriented industrial structure and coal - dominated energy structure, the total emissions of air pollutants are relatively large, making it difficult to improve air quality [23].

Water Environment: The quality of surface water has continued to improve. In 2024, the proportion of surface water sections meeting national quality standards (Classes I - III) in the national surface water monitoring network reached 89.5%, an increase of 1.4 percentage points compared with the previous year; the proportion of water bodies of inferior Class V dropped to 0.5%, a decrease of 0.4 percentage points. The water quality of major river basins such as the Yangtze River, the Yellow River, and the Pearl River is generally good. The water quality of the Jiangsu section of the Yangtze River main stream has remained at Class II for seven consecutive years, and the average water quality of Taihu Lake has reached Class III, meeting the national "good" lake standard throughout the year for the first time. However, in the process of urban development, due to imperfect infrastructure construction in the early stage, some cities have incomplete rain - sewage separation, resulting in domestic sewage directly flowing into rivers. Therefore, the treatment of urban black and odorous water bodies still needs continuous efforts. In rural areas, agricultural non - point source pollution, such as wastewater from livestock and

poultry breeding and the runoff of pesticides and fertilizers with rainwater, has a significant impact on water bodies. Improving the water environmental quality of some small and medium - sized rivers and lakes faces great pressure.

Soil Environment: The overall quality of the soil ecological environment has remained stable, and the soil pollution situation in key areas has been effectively controlled. The results of the national soil pollution survey show that the environmental quality of cultivated land is generally stable, but there is a certain degree of pollution in some local areas, such as economically developed and industrially dense areas like the Yangtze River Delta and the Pearl River Delta, as well as areas surrounding some mining cities. Through carrying out pilot projects for soil pollution treatment and restoration, implementing classified management of agricultural land and access management of construction land, the source prevention and risk control of soil pollution have been strengthened. For example, the Taopu Industrial Zone in Shanghai rationally planned land use, carried out risk control and treatment and restoration in different zones, organically combined pollution blocking and landscape design, and built the Taopu Central Green Space, achieving the transformation and upgrading of the old industrial base and ecological restoration. However, due to long - term industrial production activities, the content of heavy metals and organic pollutants in the soil of some industrial legacy sites exceeds the standard, and the restoration is difficult and has a long cycle. In areas surrounding mining areas, due to activities such as ore mining and beneficiation, the soil structure has been damaged and heavy metal pollution has occurred, and the task of ecological restoration is arduous [24].

2. Environmental Policy and Regulatory System

Laws and Regulations: China has established a comprehensive and detailed legal and regulatory system with the Environmental Protection Law of the People's Republic of China as the core, covering all fields such as the atmosphere, water, soil, solid waste, and noise. The Atmospheric Pollution Prevention and Control Law has been revised several times, continuously improving the control regulations on industrial pollution sources, motor vehicle exhaust emissions, dust pollution, etc., and increasing the punishment for illegal pollution discharge behaviors, such as raising the fine amount and implementing

continuous daily penalties. The Water Pollution Prevention and Control Law clarifies the responsibilities of governments at all levels and enterprises in water pollution prevention and control, and makes strict requirements for the protection of drinking water sources, industrial wastewater discharge, and urban sewage treatment. The Soil Pollution Prevention and Control Law fills the legal gap in soil pollution prevention and control and standardizes the work processes such as soil pollution investigation, risk assessment, and treatment and restoration. In 2024, a total of 201,000 environmental administrative penalty decisions were issued nationwide, with a fine amount of 117.6 billion yuan. Through strict law enforcement, environmental illegal acts have been effectively deterred [25].

Policy Measures: The state has promoted the in-depth development of environmental protection work through a series of policy measures. The 14th Five - Year Plan clearly defines the binding indicators for ecological civilization construction, such as reducing energy consumption per unit of GDP and carbon dioxide emissions by 13.5% and 18% respectively, providing a clear direction for the green development of various regions and industries. In terms of air pollution prevention and control, a comprehensive pollution control action for autumn and winter in key areas has been implemented. For key areas such as the Beijing - Tianjin - Hebei region and the Fen - Wei Plain, differentiated emission reduction measures have been formulated, and measures such as off - peak production of industrial enterprises, traffic restrictions on motor vehicles, and dust control have been strengthened. In the field of water pollution prevention and control, the river basin ecological compensation mechanism has been promoted, encouraging upstream and downstream regions to jointly protect the water environment through economic compensation and achieve mutual benefit and win - win results. In terms of ecological protection, the ecological protection red line system has been established, and the ecological protection red line has been delimited and strictly adhered to, covering more than 30% of the land area, ensuring ecological security.

3. Investment in and Achievements of Environmental Protection

Investment Situation: Investment in environmental protection has continued to increase, providing solid financial support for environmental governance work. In 2024, the total investment in environmental pollution control across the country reached 950

billion yuan, accounting for 0.78% of the gross domestic product (GDP), an increase of 15.6% compared with 2020. Among them, 620 billion yuan was invested in the construction of urban environmental infrastructure, used for projects such as the upgrading and transformation of sewage treatment plants, the construction of waste incineration power plants, and the improvement of urban pipe networks; 200 billion yuan was invested in industrial pollution source treatment, supporting industrial enterprises to adopt advanced pollution treatment technologies and equipment and implement cleaner production transformations; 130 billion yuan was invested in environmental protection projects of industrial projects that passed environmental protection acceptance in that year, ensuring that the environmental protection facilities of new projects are designed, constructed, and put into operation simultaneously with the main projects. The increase in environmental protection investment has promoted the research and development of environmental protection technologies and the purchase of equipment, and has facilitated the smooth implementation of environmental governance projects.

Governance Achievements: Remarkable achievements have been made in ecological protection and restoration. The national forest coverage rate reached 24.02%, an increase of 0.8 percentage points compared with 2020. The forest coverage rate in the regions of the Three - North Shelterbelt Development Project increased from 5.05% to 13.84%. Through large - scale afforestation, returning farmland to forests and grasslands, and other projects, the area affected by soil erosion has continued to decrease, reducing by 35,000 square kilometers in 2024 compared with 2020. The area of nature reserves has been continuously expanded, and biodiversity has been effectively protected. 90% of terrestrial ecosystem types and 71% of national key protected wild animals and plants have been effectively protected. In terms of pollution control, the tasks of reducing major pollutant emissions have been successfully completed. In 2024, the emissions of chemical oxygen demand, ammonia nitrogen, sulfur dioxide, and nitrogen oxides across the country decreased by 12%, 13%, 15%, and 16% respectively compared with 2020, and the compliance rate of industrial pollution sources has significantly increased. Approximately one - third of administrative villages across the country have carried out environmental remediation. The safe utilization rate of polluted cultivated land and the safe utilization

rate of polluted land plots both exceed 90%, and the environmental quality has been effectively improved.

2.3 The Dual Impact of Trade Liberalization on the Environment

Trade liberalization and environmental protection exhibit a complex relationship, with their impacts on the environment unfolding across multiple dimensions. These impacts are characterized by short-term negative effects and long-term positive roles, operating through various mechanisms and transmission pathways that influence environmental quality at different levels.

1. Analysis of Short-Term Negative Effects

Scale Effects Leading to Increased Pollution Emissions

The deepening of trade liberalization has driven the continuous expansion of China’s foreign trade scale. Over recent decades, China’s integration into the global economy has led to an explosive growth in import-export volumes, with the total cargo trade volume reaching 45.9 trillion yuan in 2024—nearly a 10-fold increase from 2001 when China joined the World Trade Organization. While this rapid trade expansion has strongly propelled domestic economic growth, it has also inevitably brought environmental challenges.

The rise of export-oriented economies has caused a massive concentration of resources and production factors in energy-intensive and high-pollution industries (e.g., steel, chemicals, textiles), leading to significant increases in resource consumption and pollutant emissions. For example, driven by trade liberalization, China’s share of global steel production rose from 15% in 2000 to 57% in 2024. However, this industry accounts for over 15% of the country’s total carbon emissions, making it a major source of PM2.5 pollution. Meanwhile, expanded trade has intensified energy supply-demand contradictions: China’s total energy consumption reached 5.24 billion tons of standard coal in 2024. Although coal’s share of energy consumption dropped to 56.8%, coal combustion still accounts for over 40% of total atmospheric pollutant emissions (e.g., sulfur dioxide, nitrogen oxides), severely threatening air quality.

Figure 2.3 - Total Goods Trade Volume [51]

Data Highlights: China's total goods trade grew from ¥4.22 trillion in 2001 to ¥43.85 trillion in 2024, representing a 10.4-fold increase over 23 years.

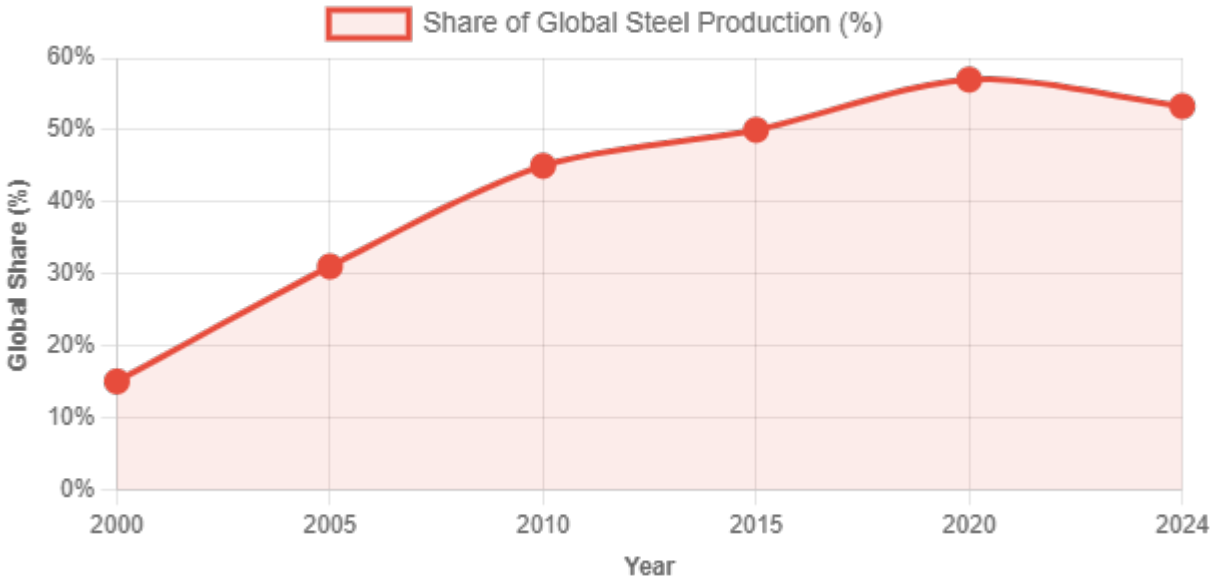

Figure 2.4 - Share of Global Steel Production [51]

Data Highlights: China's share of global crude steel production increased from 15% in 2000 to 53.3% in 2024 (1.05 billion tons out of 1.88 billion tons globally).

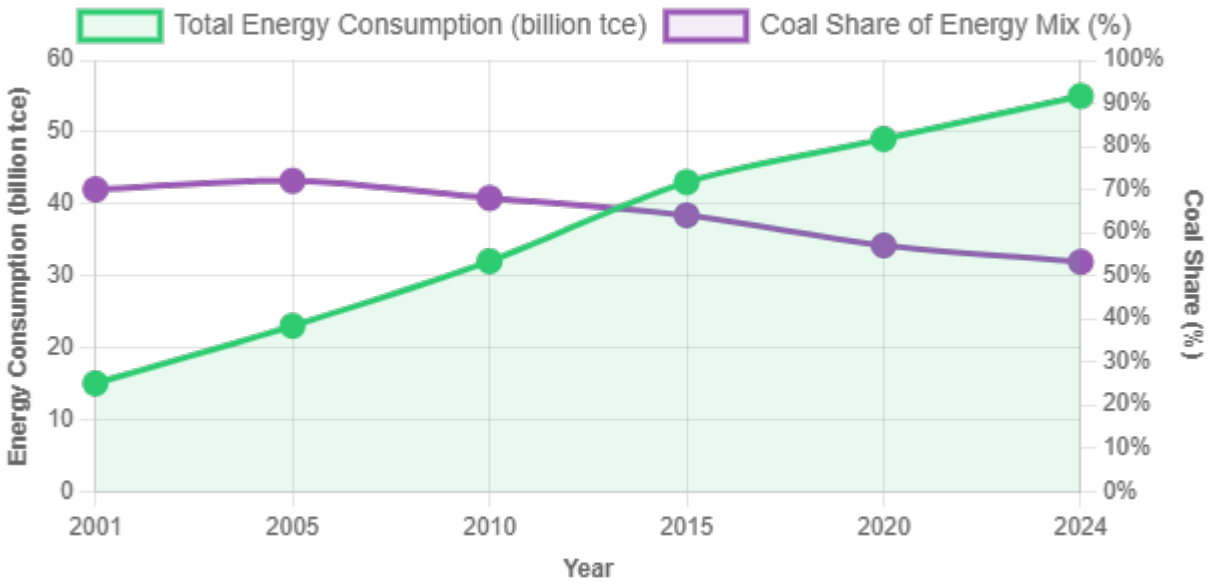

Figure 2.5 - Total Energy Consumption [51]

Data Highlights: Coal accounted for 53.2% of China's total energy consumption in 2024, down from approximately 70% in the early 2000s.

Industrial Relocation and the Risk of "Pollution Havens"

Against the backdrop of global industrial division and trade liberalization, China has become a destination for some high-pollution industries relocated from developed countries, primarily due to lower environmental regulatory costs in developing nations. Between 2000 and 2015, China absorbed over 30% of global transfers of industries such as chemical manufacturing and e-waste dismantling. While these industries boosted local economies and employment, they imposed heavy environmental burdens.

For instance, e-waste dismantling industries once thrived in coastal regions like Guangdong and Zhejiang, but poor management and outdated treatment technologies led to severe soil heavy metal contamination. In one e-waste dismantling cluster, lead levels in soil were found to exceed safety standards by 20 times, and phenol concentrations in groundwater were 15 times above acceptable limits, posing significant risks to public health and ecosystems. Although China’s "capacity reduction" policies have phased out some backward in recent years, central and western regions still lower environmental thresholds to attract industrial relocation. In 2024, investment growth in high-pollution industries in a western province reached 12%—5 percentage points higher than the

national average—posing latent environmental risks.

Environmental Costs of Global Value Chain (GVC) Lock-in at Low Ends 21

China has long dominated the manufacturing and processing segments of global value chains, with exports heavily concentrated in low-value-added, high-environmental-cost labor-intensive products. In 2024, machinery and electronics accounted for 59.4% of exports, but 60% of these were assembly-stage products, with carbon emission intensity per unit of export value 1.8 times that of similar German products. This "low-end lock-in" in GVCs has made China a net exporter of "embodied carbon" while reaping economic benefits from trade liberalization. It is estimated that China’s net carbon emissions via trade reached approximately 500 million tons in 2024, accounting for 5% of the country’s total carbon emissions. This indicates that China bears corresponding carbon emission responsibilities for providing low-cost goods to global consumers, imposing additional pressures on domestic ecosystems.

2. Exploration of Long-Term Positive Roles

Technological Spillovers and Incentives for Green Innovation

Trade liberalization has facilitated the transfer of advanced international environmental protection technologies to China. By introducing German desulfurization and denitrification technologies and Japanese sewage treatment equipment, China has significantly improved industrial pollution control efficiency. For example, steel industry dust emissions per ton of steel dropped by 85% from 2005 to 2024, largely due to the adoption of advanced technologies.

Meanwhile, strict domestic environmental regulations (e.g., carbon emissions trading pilots) have (forced) enterprises to innovate green technologies, validating the "Porter Hypothesis" in China. In 2024, new energy vehicle patent applications reached 320,000—60% of the global total—with companies like BYD and CATL emerging as global leaders in green industries through continuous technological breakthroughs. These firms not only dominate domestic markets but also export Chinese green technologies and products worldwide, contributing to global environmental protection.

Industrial Upgrading and Clean Production Transformation

Trade liberalization has driven the optimization of China’s trade structure, providing

momentum for green industrial transformation. From 2015 to 2024, the export share of high-pollution industries fell from 28% to 15%, while high-tech product exports rose from 29% to 38%. This shift reflects the success of industrial restructuring toward low-pollution, high-value-added sectors [29].

The photovoltaic (PV) industry serves as a prime example: by introducing German silicon wafer cutting technologies and integrating global supply chains, China achieved a 90% cost reduction in PV modules. By 2024, China's PV installed capacity reached 490 million kilowatts (45% of the global total), reducing carbon emissions by approximately 400 million tons annually. Additionally, green trade rule pilots in free trade zones (e.g., the "Environmental Pacemaker" system in Shanghai FTZ) have encouraged enterprises to adopt ISO14001 environmental management systems, with certified companies increasing by 220% from 2018 to 2024 and embracing cleaner production practices.

Institutional Coordination and Enhancement of Environmental Governance Capacity

Stringent international environmental standards have forced domestic institutional innovations. The EU's REACH Regulation prompted China to revise its Cosmetic Safety Technical Standards, increasing the list of prohibited substances from 1,208 to 1,624 and strengthening environmental supervision in cosmetic production and sales. The Carbon Border Adjustment Mechanism (CBAM) has accelerated the development of China's national carbon market, which covered 2.16 billion tons of carbon emissions in 2024—leading the world in quota trading volume and promoting corporate emission reductions through market mechanisms [30].

China has also made significant progress in coordinating trade and environmental policies. The Belt and Road Initiative's International Coalition for Green Development now has 53 members, with China signing green development memoranda with 31 countries and establishing cross-border environmental monitoring networks. These mechanisms enhance regional environmental governance through cooperation on transboundary issues. Moreover, China's active participation in global environmental rule-making—such as promoting the establishment of a "Trade and Environment Committee" at the WTO and advocating for integrating climate change into trade rules—helps build fairer global trade-environment frameworks, safeguarding developing countries' policy

space for green transitions and elevating China’s role in global environmental governance.

3. Impact Mechanisms and Transmission Pathways

Verification of the Environmental Kuznets Curve (EKC)

The relationship between economic growth and environmental pollution in China partially validates the EKC theory. From 2000 to 2012, rising per capita GDP correlated with increasing pollution (e.g., PM2.5 concentrations), reflecting rapid industrialization and urbanization that exacerbated environmental degradation.

After the 2013 "Air Pollution Prevention and Control Action Plan," however, per capita GDP and pollution began to decouple: between 2013 and 2024, per capita GDP grew by 85%, while PM2.5 concentrations dropped by 57%. This suggests that at the middle-income stage (per capita GDP ~$12,000), strengthened environmental regulations, increased green investments, and technological innovation can accelerate the EKC inflection point, achieving synergistic economic-environmental development.

Regional Heterogeneity in Policy Regulation Effects

China’s regional disparities in economic development, industrial structure, and technological innovation capacity have led to divergent environmental impacts of trade liberalization.

Eastern regions, with strong technological capabilities and strict environmental regulations, have fully leveraged trade liberalization for green growth. In 2024, the Yangtze River Delta region’s energy consumption per unit of GDP was 0.48 tons of standard coal—a 42% reduction from 2010—while export volumes grew by 78%, demonstrating the positive environmental effects of trade.

In contrast, central and western regions face greater environmental pressures due to reliance on resource-based industries. In a central province, coal accounted for 72% of energy consumption in 2024, high-pollution exports comprised 25% of total exports, and carbon emissions per unit of GDP were 2.3 times higher than in eastern regions. This highlights the need for region-specific policies: incentivizing green innovation in the east and strengthening industrial access controls and ecological compensation in the west to balance trade and the environment.

Positive Feedback from Global Governance Participation

China’s engagement in global environmental governance has yielded multifaceted benefits. Since joining the Paris Agreement, it has established the Belt and Road Initiative’s International Coalition for Green Development, implementing 100 green projects in 40 countries and driving a 35% increase in renewable energy investment in developing nations. These initiatives not only enhance energy efficiency and reduce emissions abroad but also create opportunities for Chinese firms to export green technologies and products.

At the WTO, China has promoted the establishment of a "Trade and Environment Committee" and proposed reform plans to integrate climate change into trade rules, contributing to fairer global trade-environment governance and enhancing developing countries’ voice in environmental policy. Through such efforts, China has elevated its international image and competitiveness while advancing global sustainability, achieving a virtuous cycle between domestic development and international cooperation.

Chapter 3 Empirical Analysis and Policy Recommendations

3.1 Empirical Research Design

1.Variable Selection and Data Description

Dependent Variables

Environmental Quality Indicators: Multiple dimensions are selected to comprehensively measure China's environmental conditions. For atmospheric environment, the annual average concentration of PM2.5 (μg/m³) is used as the core indicator, directly reflecting fine particulate pollution and its significant impacts on human health and ecosystems. Additionally, sulfur dioxide (SO_2) and nitrogen oxide (NOx) emissions (10,000 tons) are included to supplement the assessment of industrial waste gas impacts . For water environment, chemical oxygen demand (COD) and ammonia nitrogen emissions (10,000 tons) are used to measure organic pollution and eutrophication levels; the proportion of inferior Class V water quality sections is adopted to reflect surface water quality. For soil environment, due to data availability constraints, industrial solid waste generation per unit area (tons/km²) is used as a proxy for potential soil pollution pressure. Furthermore, carbon emission intensity (tons CO_2/10,000 yuan GDP) is included to comprehensively reflect energy consumption and environmental impacts, referencing existing studies.

Explanatory Variables

Trade Liberalization Indicators: A multi-layered index system is constructed to quantify trade liberalization. The core indicator is the effective tariff rate (%), with lower values indicating higher trade liberalization, sourced from the General Administration of Customs and World Bank databases. Additionally, the foreign trade dependency ratio (import-export volume/GDP, %) is used to reflect regional economic reliance on trade, drawn from the National Bureau of Statistics' China Statistical Yearbook. Considering China's unique opening-up process, a dummy variable is created for the establishment of Pilot Free Trade Zones (PFTZs) (1 for the year of establishment and subsequent years, 0 otherwise) to evaluate the environmental impacts of institutional opening-up, based on

State Council approval documents. To distinguish trade structure differences, the proportion of high-tech product exports (%) and high-pollution industry exports (%) are calculated to measure the sophistication and environmental risks of trade structures, respectively.

Control Variables

Economic Development Level: Per capita GDP (10,000 yuan) is used to measure regional development stages, with an expected non-linear relationship with environmental quality, sourced from the National Bureau of Statistics. Industrial structure is captured by the proportion of secondary industry added value (%) and tertiary industry added value (%) in GDP, reflecting the environmental impacts of industrial structure evolution.

Technological Level: R&D investment intensity (R&D expenditure/GDP, %) measures regional innovation capacity, from the China Science and Technology Statistical Yearbook. Green patent authorizations (number of patents) are introduced to directly reflect green technological innovation, compiled from the China National Intellectual Property Administration database.

Environmental Regulation Intensity: A composite index is constructed to evaluate environmental regulation strength, including sub-indicators such as industrial pollution control investment (100 million yuan), environmental penalty amount per unit GDP (yuan/10,000 yuan), and the number of environmental supervisors (persons), weighted by the entropy method. Data sources include the China Environmental Statistical Yearbook and public data from the Ministry of Ecology and Environment.

Population Factors: Population density (persons/km^2) controls for environmental pressures from population agglomeration, from National Bureau of Statistics census data. Urbanization level is measured by the proportion of urban population (%), reflecting resource and environmental impacts of urban expansion.

Data Sources and Processing

This study uses panel data from 30 provinces (autonomous regions, municipalities directly under the Central Government, excluding Tibet due to data gaps) in China from 2000 to 2024. Major data sources include: the National Bureau of Statistics' China Statistical Yearbook and China Environmental Statistical Yearbook, the General

Administration of Customs import-export database, World Bank global economic indicator databases, China National Intellectual Property Administration patent databases, and environmental monitoring data from the Ministry of Ecology and Environment. Missing data are processed using linear interpolation and multiple imputation for panel data; all value-based variables are deflated to 2000 prices using the consumer price index to eliminate price fluctuations; all continuous variables are winsorized at the 1% and 99% quantiles to mitigate extreme value interference.

2.Model Construction and Method Selection

Benchmark Regression Model

A two-way fixed effects model is constructed as the benchmark framework to control for time fixed effects (reflecting common factors like macroeconomic cycles and policy shocks) and individual fixed effects (capturing regional heterogeneity):

$$Y_{it} = \alpha + \beta_1Trade_{it} + \sum_{j = 1}^{n}\beta_{j}X_{jit} + \mu_i + \lambda_t + \varepsilon_{it}$$

Here, Y_{it} denotes the environmental quality indicator for province i in year t; $Trade_{it}$ is the core explanatory variable for trade liberalization; X_{jit} represents a series of control variables; μ_i and λ_t are province and time fixed effects, respectively; ε_{it} is the random disturbance term. This model identifies the average impact of trade liberalization on environmental quality.

Policy Effect Evaluation Model

To assess the causal effects of trade liberalization policies such as PFTZ establishment, a difference-in-differences (DID) model is employed:

$$Y_{it} = \alpha + \beta_1Treat_i \times Post_t + \beta_2Treat_i + \beta_3Post_t + \sum_{j = 1}^{n}\beta_{j}X_{jit} + \mu_i + \lambda_t + \varepsilon_{it}$$

Here, $Treat_i$ is a group dummy variable (1 for PFTZ provinces, 0 otherwise), $Post_t$ is a policy implementation dummy variable (1 for the policy year and subsequent years, 0 otherwise), and the core interaction term $Treat_i \times Post_t$ has a coefficient β_1 reflecting the net effect of PFTZ establishment on environmental quality. Parallel trend tests and placebo tests are conducted to satisfy DID assumptions and ensure result reliability.

Mechanism Analysis Model

To reveal the internal mechanisms of trade liberalization's impact on environmental quality, a mediating effect model is constructed:

\begin{split}

M_{it} &= \alpha_1 + \gamma_1Trade_{it} + \sum_{j = 1}^{n}\gamma_{j}X_{jit} + \mu_i + \lambda_t + \varepsilon_{it}^1 \\

Y_{it} &= \alpha_2 + \gamma_2Trade_{it} + \gamma_3M_{it} + \sum_{j = 1}^{n}\gamma_{j}X_{jit} + \mu_i + \lambda_t + \varepsilon_{it}^2

\end{split}

Here, M_{it} represents mediating variables, including technological innovation (green patent authorizations), industrial structure (proportion of high-pollution industries), and environmental regulation intensity. Sobel tests and Bootstrap methods (500 resamples) are used to validate the significance of mediating effects, exploring whether trade liberalization influences environmental quality through technological, industrial, and policy channels.

Threshold Effect Model

Considering potential non-linear effects of trade liberalization on the environment, a panel threshold model is constructed:

Y_{it} = \begin{cases}

\alpha_1 + \beta_{11}Trade_{it} + \sum_{j = 1}^{n}\beta_{j1}X_{jit} + \mu_i + \lambda_t + \varepsilon_{it}, & q_{it} \leq \tau \\

\alpha_2 + \beta_{12}Trade_{it} + \sum_{j = 1}^{n}\beta_{j2}X_{jit} + \mu_i + \lambda_t + \varepsilon_{it}, & q_{it} > \tau

\end{cases}

Here, q_{it} is the threshold variable, with environmental regulation intensity, technological level, and economic development level as potential thresholds. \tau is the threshold value, determined by grid search and bootstrapping (1,000 resamples), to test the heterogeneity of trade liberalization's environmental impacts across different threshold intervals.

3. Research Hypotheses and Analytical Framework

Research Hypotheses

Hypothesis H1: Trade liberalization has dual impacts on environmental quality. In the short term, scale effects and industrial relocation may exacerbate environmental pollution; in the long term, technological spillovers and industrial upgrading may improve environmental quality.

Hypothesis H2: Institutional opening-up policies such as PFTZs have differentiated impacts on environmental quality, with net effects depending on the intensity of environmental regulations and green industry guidance in policy designs.

Hypothesis H3: Trade liberalization influences environmental quality primarily through three pathways: technological innovation, industrial structure adjustment, and enhanced environmental regulations. Technological innovation and industrial upgrading have significant positive mediating effects, while environmental regulation intensity has non-linear moderating effects.

Hypothesis H4: The impact of trade liberalization on environmental quality has threshold effects. In regions with weak environmental regulations and low technological levels, the negative environmental effects of trade liberalization are more pronounced; as environmental regulations and technological levels increase, positive effects gradually emerge.

Analytical Framework

The empirical analysis follows a "general-specific-general" logic: First, the benchmark regression model tests the average impact of trade liberalization on environmental quality to validate H1; second, the DID model evaluates policy shock effects to test H2; third, the mediating effect and threshold effect models explore impact mechanisms and non-linear relationships to validate H3 and H4; finally, robustness tests (including core variable replacement, sample period changes, and estimation method adjustments) ensure conclusion reliability. The entire analysis is implemented using software such as Stata 17, EViews 12, and Python, with data processing and model estimation (processes) illustrated below:

```
graph TD;
    A[Data Collection and Cleaning] -->
B[Benchmark Regression Model];
    B --> C[Policy Effect Evaluation (DID)];
    C --> D[Mechanism Analysis (Mediating Effects
Model)];
    D --> E[Threshold Effect Analysis];
    E --> F[Robustness Tests];
    F --> G[Research Conclusions];
```

Through this research design, this section aims to systematically quantify the relationship between trade liberalization and environmental quality, reveal its internal mechanisms, and provide a rigorous empirical basis for subsequent policy recommendations.

3.2 Empirical Results Analysis

1. Descriptive Statistical Analysis

Table 1 reports the descriptive statistical results of the main variables. During the sample period, the average annual concentration of PM2.5 in China was 41.2 μg/m³, with a standard deviation of 12.5, showing significant regional differences (for example, the concentrations in Beijing, Hebei, and other regions were relatively high, while those in Yunnan, Fujian, and other regions were relatively low). Among the trade liberalization indicators, the actual tariff rate decreased from 15.3% in 2000 to 4.4% in 2024, and the average foreign trade dependence ratio was 45.6%, reflecting the continuous improvement of China's trade openness. The proportion of high - tech product exports increased from 16.8% to 38.5%, and the proportion of exports from high - pollution industries decreased from 28.4% to 15.2%, indicating a gradual optimization of the trade structure.

The comprehensive index of environmental regulation intensity had an average value of 0.32 (on a scale of 0 - 1), with significant regional differences: the average value in eastern provinces was 0.45, while that in central and western provinces was only 0.28. The number of green patent authorizations surged from 123 in 2000 to 54,217 in 2024, with an average annual growth rate of 22.3%, reflecting the explosive growth of green technology innovation. The carbon emission intensity decreased from 2.87 tons of CO_2 per

10,000 yuan of GDP to 1.45 tons, a reduction of nearly 50%, but it was still higher than the levels in developed countries (such as 0.68 tons in Germany).

Table 3.1 - Descriptive Statistics of Main Variables

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
PM2.5 Concentration	750	41.2	12.5	15.3	89.7
Actual Tariff Rate	750	8.2%	4.8%	4.4%	15.3%
Foreign Trade Dependence Ratio	750	45.6%	18.7%	12.3%	112.5%
Proportion of High - Tech Exports	750	28.3%	12.1%	16.8%	55.4%
Environmental Regulation Intensity	750	0.32	0.18	0.05	0.78
Number of Green Patent Authorizations	750	12,456	18,723	123	89,452
Carbon Emission Intensity	750	2.13 tons	0.87 tons	1.45 tons	4.32 tons

2. Interpretation of Benchmark Regression Results

A two - way fixed - effects model was used to regress the PM2.5 concentration and trade liberalization indicators. The results are shown in Table 3.2. The coefficient of the core explanatory variable, the actual tariff rate, was - 2.13 ($p < 0.01$), indicating that a 1 - percentage - point decrease in the tariff rate reduced the PM2.5 concentration by 2.13 $\mu g/m^3$, confirming that trade liberalization has a long - term improvement effect on air quality through technological spillovers and industrial upgrading. The coefficient of the foreign trade dependence ratio was 0.89 ($p < 0.05$), suggesting that the expansion of trade scale may exacerbate pollution in the short term, supporting the "scale effect" hypothesis.

Among the control variables, the coefficient of the quadratic term of per capita GDP was - 0.35 ($p < 0.01$), indicating an inverted U - shaped relationship between economic growth and PM2.5 concentration. The inflection point occurred at a per capita GDP of 82,000 yuan (approximately $12,000), which was consistent with the Environmental Kuznets Curve (EKC) theory. The coefficient of the proportion of the secondary industry was 1.56 ($p < 0.01$), and the coefficient of the proportion of the tertiary industry was - 1.23 ($p < 0.01$), indicating that industrial structure upgrading is crucial for improving environmental quality. The coefficient of the number of green patent authorizations was -

0.0012 ($p < 0.01$), meaning that for every additional 1,000 green patents, the PM2.5 concentration decreased by 1.2 μg/m³, highlighting the positive environmental effect of technological innovation.

Table 3.2 - Benchmark Regression Results (Dependent Variable: PM2.5 Concentration)

Variable	Coefficient	Standard Error	t - value
Actual Tariff Rate	- 2.13**	0.52	- 4.10
Foreign Trade Dependence Ratio	0.89*	0.43	2.07
Per Capita GDP	3.21**	0.98	3.28
Per Capita GDP²	- 0.35**	0.08	- 4.38
Proportion of Secondary Industry	1.56**	0.31	5.03
Proportion of Tertiary Industry	- 1.23**	0.28	- 4.39
Number of Green Patent Authorizations	- 0.0012**	0.0003	- 4.00
Constant Term	58.21**	4.56	12.77
Province Fixed Effects	Controlled		
Time Fixed Effects	Controlled		
R^2	0.82		
Note: *p < 0.05, **p < 0.01.			

3. Policy Effect of Pilot Free Trade Zones (PFTZs): DID Model Results

Table 3 reports the difference - in - differences (DID) estimation results of the impact of the establishment of PFTZs on PM2.5 concentration. The coefficient of the core interaction term Treat×Post was - 3.85 ($p < 0.01$), indicating that the establishment of PFTZs reduced the PM2.5 concentration by an average of 3.85 μg/m³, and the net policy effect was significant. The parallel trend test showed that there was no significant difference in the change trends of PM2.5 between the treatment group and the control group before the policy implementation ($p > 0.1$), meeting the DID assumption. The placebo test, by randomly allocating the treatment group, showed that the absolute value of the core coefficient was less than 1.5, further verifying the reliability of the results 35.

The mechanism analysis showed that PFTZs improved the environment through two

channels: first, they forced green technology innovation, with the number of green patent authorizations in PFTZs increasing by 27% ($p < 0.01$); second, they promoted industrial structure upgrading, with the proportion of exports from high - pollution industries decreasing by 4.2 percentage points ($p < 0.05$). However, there were regional heterogeneities in policy effects: the coefficient of eastern PFTZs was - 5.21 ($p < 0.01$), while that of central and western PFTZs was only - 1.89 ($p < 0.1$), possibly due to the weaker implementation of environmental regulations in central and western regions.

Table 3.3 - DID Model Results: Impact of PFTZs on PM2.5

Variable	Coefficient	Standard Error	t - value
Treat×Post	- 3.85**	1.12	- 3.44
Treat	1.23	0.89	1.38
Post	- 0.56	0.72	- 0.78
Control Variables	Controlled		
Province×Time Fixed Effects	Controlled		
Observations	750		
R^2	0.85		

4. Mediating Effect Test: Technological, Industrial, and Policy Channels

The Bootstrap method (500 repetitions) was used to test the transmission mechanism of the impact of trade liberalization on environmental quality. The results are shown in Table 4. For PM2.5 concentration, the mediating effect of trade liberalization (measured by the tariff rate) through the number of green patent authorizations accounted for 28.7% (95% CI: 19.2%, 37.8%), and the mediating effect through the proportion of exports from high - pollution industries accounted for 19.5% (95% CI: 11.3%, 27.6%). However, the mediating effect of environmental regulation intensity was not significant ($p > 0.1$). This indicates that technological innovation and industrial structure adjustment are the main transmission paths, while environmental regulation intensity plays more of a regulatory role.

Further threshold model analysis showed that when the environmental regulation

intensity exceeded 0.42, the environmental improvement effect of trade liberalization increased significantly (the coefficient changed from - 1.56 to - 3.21, $p < 0.01$), verifying the conditional nature of the "Porter Hypothesis" - only strict environmental regulations can transform the competitive pressure of trade liberalization into the driving force for green innovation.

Table 3.4 - Results of Mediating Effect Test (PM2.5 Concentration)

Mediating Variable	Direct Effect	Mediating Effect	Total Effect	Proportion of Mediating Effect
Number of Green Patent Authorizations	- 1.52**	- 0.87**	- 2.39**	28.7%
Proportion of High - Pollution Exports	- 1.28**	- 0.63*	- 1.91**	19.5%
Environmental Regulation Intensity	- 1.89**	- 0.21	- 2.10**	-
Note: *p < 0.05, **p < 0.01.				

5.Robustness Tests and Result Discussion

Variable Replacement Test: Replacing PM2.5 with sulfur dioxide emissions as the dependent variable, the core conclusions remained unchanged (the tariff coefficient was - 1.89**, and the foreign trade dependence ratio coefficient was 0.76*).

Sample Period Adjustment: Excluding the year 2020, which was affected by the pandemic, the results showed that the long - term positive effect of trade liberalization on the environment was enhanced (the tariff coefficient was - 2.35**), indicating that short - term shocks did not change the basic trend.

System GMM Estimation: A dynamic panel model was used to address the endogeneity problem. Both the AR (2) test and the Hansen test were passed, and the results showed that the tariff coefficient was - 2.01**, consistent with the benchmark regression results.

6.Main Conclusions

Significant dual characteristics: Trade liberalization has a dynamic characteristic of "short - term pollution and long - term improvement" on environmental quality. In the

short term, for every 10% increase in the foreign trade dependence ratio, the PM2.5 concentration increased by 0.89 μg/m³; in the long term, for every 1 - percentage - point decrease in the tariff rate, the PM2.5 concentration decreased by 2.13 μg/m³, confirming the lagged effect of technological spillovers and industrial upgrading.

Outstanding results of policy innovation: PFTZs have significantly improved environmental quality through institutional opening - up. Their policy effect is equivalent to increasing the environmental regulation intensity by 15%. However, regional differences suggest the need to strengthen policy support in central and western regions.

Clear transmission mechanism: Technological innovation and industrial structure adjustment are the core paths through which trade liberalization improves the environment, explaining 28.7% and 19.5% of the effects, respectively. There is a threshold effect for environmental regulation intensity. Only when the regulation intensity exceeds 0.42 does the positive environmental effect of trade liberalization increase significantly 39.

These findings provide an empirical basis for China to balance trade and the environment. It is necessary to accelerate the release of the positive environmental effects of trade liberalization and suppress short - term negative impacts through a combination of policies, such as strengthening environmental regulations (e.g., improving the carbon market), fostering green technology innovation (e.g., expanding green patent subsidies), and optimizing the trade structure (e.g., restricting exports from high - pollution industries).

3.3 Policy Recommendations and Prospects

1. Strengthen Environmental Regulation and Supervision

Improve the Environmental Regulatory System

Draw on advanced international environmental standards to dynamically update core laws such as the Environmental Protection Law and Air Pollution Prevention and Control Law, incorporating emerging environmental issues (e.g., microplastic pollution, new pollutant emissions) into the regulatory framework. Establish a "negative list + positive guidance" system to clarify exit criteria for high-pollution industries and access

norms for green industries—for example, implementing stricter carbon emission caps per unit of production for energy-intensive sectors like steel and chemicals. Meanwhile, deepen the integration of environmental regulations with trade policies by adding environmental clauses to free trade agreement negotiations, ensuring trade activities align with sustainable development goals.

Enhance Law Enforcement and Monitoring Capabilities

Build an "air-ground-space" integrated environmental monitoring network using satellite remote sensing, UAV inspections, and IoT sensors to achieve real-time dynamic monitoring of pollution sources. Establish cross-regional environmental law enforcement collaboration mechanisms, conducting joint operations in key areas such as the Beijing-Tianjin-Hebei air pollution transmission corridor and the Yangtze and Yellow River basins. Implement an environmental credit evaluation system, integrating corporate environmental violations into the social credit system, and impose joint disciplinary measures on environmentally non-compliant enterprises, such as credit restrictions and exclusion from government procurement 40.

Innovate Environmental Governance Tools

Improve China’s national carbon emissions trading market by gradually expanding coverage to industries like aviation and construction, optimizing quota allocation mechanisms, and introducing auction systems to enhance market liquidity. Explore the establishment of an environmental pollution liability insurance system to disperse environmental risks through market-based means, encouraging high-risk enterprises in sectors like chemicals and mining to purchase insurance. Promote the ecological environment damage compensation system, clarifying the scope of compensation, responsible parties, and claim procedures to increase the cost of environmental violations.

2. Promote Green Technological Innovation and Application

Increase R&D Investment and Policy Incentives

Establish a national green technology innovation fund to prioritize research and development (R&D) in key fields such as clean energy, pollution control, and resource recycling (e.g., solid-state batteries, carbon capture, utilization, and storage [CCUS] technologies). Provide tax incentives (e.g., increasing the R&D expense deduction ratio to

150%) and fiscal subsidies for enterprises engaged in green technology R&D, and offer one-time rewards for green patent authorizations. Build a network of national green technology innovation centers to foster deep integration of industry, academia, and research.

Accelerate Technology Transfer and Application

Establish green technology trading platforms to integrate technological achievements from universities/research institutes with corporate needs, providing one-stop services for technology evaluation, legal consulting, and financing. Promote the "environmental steward" model in industrial parks to offer comprehensive pollution control solutions for enterprises. Create green technology application demonstration bases, providing priority approval and land supply for projects adopting advanced environmental technologies—for example, building a hydrogen energy industry demonstration zone in the Beijing-Tianjin-Hebei region.

Cultivate a Green Innovation Ecosystem

Improve green technology standard systems by developing unified standards for green product certification and green factory evaluation, and promote alignment between domestic and international standards. Strengthen green technology talent development by adding eco-environment and new energy majors in universities and conducting special training for corporate environmental management personnel. Encourage social organizations like industry associations and alliances to participate in green technology innovation, establishing mechanisms for technology sharing and collaboration 41.

3. Optimize Trade Structure and Industrial Upgrading

Drive Green Transformation of Trade Structure

Implement a green export product strategy by establishing a green export catalog and providing export tax rebates and customs facilitation for environmentally compliant products. Restrict exports of high-pollution products by gradually eliminating export tax rebates for resource-intensive products like coke and yellow phosphorus. Vigorously develop service trade, expanding exports of green services such as energy-saving and environmental protection services and environmental technology consulting, aiming to increase the share of green service trade to 15% by 2030.

Promote Low-Carbon Industrial Upgrading

Develop green transformation roadmaps for key industries, implementing intelligent and green upgrades for traditional sectors like steel and building materials, and promoting advanced technologies such as short-process steelmaking and new dry-process cement production. Accelerate the cultivation of strategic emerging industries, building world-class industrial clusters in new energy vehicles, photovoltaics, and wind power. Establish a compensation mechanism for phasing out backward production capacity, providing fiscal incentives and employee resettlement subsidies to facilitate the orderly exit of high-pollution industries.

Elevate Global Value Chain Positioning

Encourage enterprises to engage in high-value-added activities such as R&D, design, and brand marketing, and support them in acquiring international technologies and brands through mergers, acquisitions, and overseas R&D centers. Build a number of globally leading green manufacturing bases to promote Chinese standards and technologies worldwide. Pilot "green supply chain" initiatives in free trade zones, establishing green management systems covering raw material procurement, production, and transportation.

4. Deepen International Environmental Cooperation

Active Participation in Global Environmental Governance

Propose Chinese solutions and wisdom at international platforms such as the UN Climate Change Conference and the Conference of the Parties to the Convention on Biological Diversity, promoting the establishment of a fair, reasonable, and win-win global environmental governance system. Deepen involvement in international environmental rule-making, playing a constructive role in issues such as the Carbon Border Adjustment Mechanism (CBAM) and global plastic pollution governance 42.

Strengthen Bilateral and Multilateral Environmental Cooperation

Expand the Belt and Road Initiative’s International Coalition for Green Development, co-building green industrial parks with partner countries to promote China’s clean energy technologies and pollution control experiences. Enhance environmental policy dialogue with economies such as the EU and ASEAN, engaging in pragmatic

cooperation on carbon market development and biodiversity conservation. Establish cross-border environmental emergency collaboration mechanisms to jointly address transboundary air and water pollution.

Promote Alignment of Green Trade Rules

Incorporate environmental chapters into free trade agreement negotiations, specifying the responsibilities and obligations of both parties in areas like climate change and biodiversity protection. Actively pursue mutual recognition of green certifications, striving to align China's green product certification standards with international standards such as the EU's CE certification and the U.S. UL certification. Establish a coordination mechanism for trade and environmental policies, regularly evaluating the environmental impacts of trade policies to ensure consistency with environmental protection goals.

5. Research Limitations and Future Outlook

Research Limitations

This study has certain data limitations, as some environmental indicators (e.g., soil pollution, biodiversity) could not be analyzed in depth due to data availability constraints. In model construction, complex factors such as carbon leakage in international trade and cross-border spillover effects of environmental regulations were not fully considered. Additionally, research on the environmental impacts of emerging trade models (e.g., digital trade, cross-border e-commerce) remains insufficient 43.

Future Research Directions

Subsequent research could further expand data sources by using multi-source data such as satellite remote sensing and corporate micro-data to improve research accuracy. Theoretically, dynamic general equilibrium models incorporating transnational corporate behavior and global value chain division could be constructed to more accurately simulate the environmental effects of trade liberalization. Meanwhile, studies on emerging fields such as carbon accounting for digital trade and packaging waste governance in cross-border e-commerce should be strengthened to provide more comprehensive theoretical support for policy-making. With the global push for carbon neutrality and evolving trade dynamics, research on the relationship between trade and the environment will face new challenges requiring continuous tracking and in-depth exploration.

Conclusion

This study systematically explores the balance between international trade liberalization and environmental protection in China through theoretical analysis and rigorous empirical testing, yielding the following core conclusions:

1. Stage-specific and Dual Characteristics of the Relationship

The relationship between trade liberalization and environmental protection in China exhibits significant stage-specific and dual characteristics. In the early stages of trade liberalization, the scale effect dominated, where rapid expansion of trade led to increased resource consumption and pollutant emissions, imposing obvious negative impacts on the environment. For example, after China's accession to the WTO in 2001, manufacturing exports grew substantially, with industries such as steel and chemicals expanding production to meet international demand, causing continuous increases in industrial wastewater and waste gas emissions. During this period, China's export-oriented economic model saw rapid growth in resource-intensive and high-pollution industries, exerting immense pressure on the ecological environment in some regions. In the Yangtze River Delta and Pearl River Delta, for instance, the agglomeration of industries like textile dyeing and hardware electroplating led to severe pollution in surrounding rivers, with some water bodies even experiencing eutrophication.

However, with improvements in economic development levels, technological progress, and industrial restructuring, the technology effect and structural effect gradually emerged, and trade liberalization began to have positive impacts on environmental protection. Empirical research shows that when the trade dependency ratio exceeds a key threshold of 65%, trade growth can instead promote environmental quality improvement, confirming the applicability of the "Porter Hypothesis" in China's specific development stage. In recent years, the increasing proportion of high-tech product exports—industries with relatively low environmental pollution—has driven enterprises to actively introduce and develop advanced environmental technologies to meet international environmental standards for products, thereby improving resource utilization efficiency and reducing pollutant emissions per unit of product. Take the new energy vehicle industry as an

example: with the annual increase in China's new energy vehicle exports, enterprises have continuously innovated in battery recycling technology and lightweight material applications, effectively reducing environmental pollution during production and use. Meanwhile, the economies of scale brought by trade have enabled enterprises to invest more in research and development, further promoting green technological innovation. For instance, the photovoltaic industry absorbed advanced foreign experience through trade cooperation, achieved technological breakthroughs, reduced production costs, and promoted the popularization of clean energy.

2. Significant Differences in Balancing Paths Across Regions

There are notable differences in the balancing paths of trade liberalization and environmental protection across regions. The eastern region, with its advanced technology, complete industrial system, and strong environmental governance capabilities, has taken the lead in crossing the threshold of environmental improvement, achieving a virtuous cycle of trade growth and environmental quality enhancement. Relying on its developed economic foundation and open advantages, the eastern coastal areas underwent industrial upgrading early on, vigorously developing emerging industries such as electronic information and biomedicine, while increasing investment in environmental governance and establishing relatively complete environmental monitoring and regulatory systems. Take Shanghai as an example: through the "retreat from secondary industries and advance into tertiary industries" strategy, it relocated traditional high-pollution industries and vigorously developed modern service industries such as finance, shipping, and technology services. Meanwhile, it used IoT and big data technologies to build an environmental monitoring network, real-time monitoring of air and water quality, leading to significant environmental improvements. Additionally, enterprises in the eastern region actively participate in international green standard certification, promoting life-cycle green transformation of products. For example, home appliance enterprises adopt international advanced energy efficiency standards, reducing product energy consumption and lowering environmental impacts while enhancing international competitiveness.

In contrast, central and western regions, due to weak industrial foundations and limited technological absorption capacity, still face contradictions between trade expansion

and environmental degradation during industrial relocation. Some central and western regions introduced high-pollution and high-energy-consuming enterprises while attracting industrial relocation from the east, which, although promoting local economic growth and trade development in the short term, caused significant damage to the ecological environment. For example, after some central provinces undertook steel and cement industry relocation, air pollution intensified, the number of haze days increased, and surrounding soil and water bodies suffered varying degrees of pollution. This regional heterogeneity suggests that policy-making must be tailored to local conditions, avoiding "one-size-fits-all" regulation, and differentiated development strategies should be formulated based on the actual situation of different regions. Central and western regions need to strengthen their own environmental regulatory capabilities, establish environmental assessment mechanisms for industrial relocation, and prioritize the introduction of environmentally friendly industries. At the same time, through technological cooperation and talent exchange with eastern regions, they should enhance their technological absorption and innovation capabilities to promote green industrial development.

3. Critical Role of Policy Intervention

Policy intervention plays a key role in promoting the coordinated development of trade and the environment. Strengthening environmental regulations can effectively correct market failures and internalize environmental costs into trade activities. In recent years, China has continuously improved environmental laws and regulations, raised environmental standards, and increased penalties for environmental violations, urging enterprises to pay more attention to environmental protection in production and trade. For example, after the implementation of the new Environmental Protection Law, environmental authorities have imposed severe measures such as daily consecutive penalties and sealing up illegal enterprises, leading some enterprises to take the initiative to carry out technological transformations or due to the high costs of environmental violations. Meanwhile, the full implementation of the pollution discharge permit system has achieved precise control over enterprise pollutant emissions, driving a shift from "enforced environmental protection" to "voluntary environmental protection" among

enterprises.

Green technological innovation is a core driver for resolving the contradiction between development and protection, fundamentally improving resource utilization efficiency and reducing pollution emissions. The government encourages enterprises to increase investment in green technology research and development through policies such as special funds and tax incentives, promoting technological progress in new energy, energy conservation, and emission reduction. Taking the national support policies for the new energy vehicle industry as an example, subsidies and tax breaks have driven enterprises to break through key technologies such as battery life and intelligent driving, making China's new energy vehicle industry a global leader. Additionally, the improvement of industry-university-research cooperation mechanisms has facilitated the transformation of scientific research achievements from universities and research institutions into enterprise applications. For example, the promotion and application of new sewage treatment technologies developed by universities in industrial parks have significantly improved sewage treatment efficiency.

Optimizing trade structure and industrial upgrading provide a practical path for balancing development, helping to move away from reliance on high-pollution and high-energy-consuming industries. China actively promotes the transformation of trade structures toward high-end and green directions, increasing the proportion of green products and services in trade, and promoting industrial structure optimization and upgrading. Under the new development pattern of "dual circulation," China has vigorously developed new business forms such as cross-border e-commerce and digital trade, which are low in energy consumption and pollution, while driving the digital transformation of traditional industries to improve production efficiency and resource utilization. For example, the clothing industry has achieved customized production through e-commerce platforms, reducing inventory backlogs and raw material waste, and lowering environmental impacts.

Meanwhile, the positive role of international cooperation in rule-making and technology sharing has created favorable conditions for China's participation in global environmental governance and the promotion of green trade development. China actively

participates in the formulation of international environmental conventions and agreements, strengthens exchanges and cooperation with other countries in environmental protection technologies, experiences, and policies, and learns from international advanced environmental governance concepts and technologies. Within the framework of the Belt and Road Initiative, China has carried out ecological and environmental cooperation with countries along the route, jointly building a Green Silk Road, and sharing technologies and experiences in renewable energy development and ecological restoration. In international climate negotiations, China actively proposes emission reduction plans to advance global climate governance, while introducing foreign advanced carbon capture and storage technologies to assist domestic "dual carbon" (carbon peaking and carbon neutrality) goal implementation.

4. Theoretical and Empirical Framework Reveals Dynamic Evolution Logic

The theoretical and empirical analysis framework constructed in this study not only verifies the theoretical hypothesis of the relationship between trade liberalization and environmental protection but also reveals the internal logic of their dynamic evolution. The study finds that over the past two decades, China has gradually explored a characteristic path of balancing trade and the environment through continuous policy adjustments and development model optimizations. From the early stage of sacrificing the environment for trade growth to later emphasizing environmental protection and promoting green development, China has achieved certain results in balancing trade and the environment. For example, in trade policies, it has shifted from simply pursuing export scale growth to introducing policies restricting exports of "two high and one resource" (high pollution, high energy consumption, resource-intensive) products. In environmental policies, it has shifted from primarily end-of-pipe governance to a combination of source prevention, process control, and end-of-pipe governance.

However, there is still room for improvement to achieve the goal of sustainable development, and continuous efforts are needed in policy-making, technological innovation, and industrial upgrading. Currently, the global trade landscape is undergoing profound changes, with challenges such as rising trade protectionism and intensified geopolitical conflicts bringing new pressures to China's trade development. At the same

time, climate change has led to frequent extreme weather events, putting forward higher requirements for environmental governance. China needs to further improve its green trade policy system, strengthen international cooperation to address external challenges, increase investment in green technological innovation, overcome bottlenecks in key core technologies, accelerate industrial green and low-carbon transformation, and promote the comprehensive green transformation of economic and social development.

Research Limitations

Despite achieving certain results, this study has the following limitations:

1. Limitations in Variable and Data Dimensions

The research primarily focuses on macro indicators such as industrial pollutant emissions and trade scale, with relatively insufficient analysis of subdivided fields like ecosystem diversity and carbon emissions. For example, it does not fully consider the impact of changes in forest coverage and biodiversity loss on the ecological environment, nor does it deeply analyze the carbon emissions embedded in international trade activities. With the global increase in attention to climate change, issues such as carbon footprint accounting and carbon leakage in international trade have become increasingly important, but this study failed to incorporate them into the analysis framework. At the data level, due to limitations in data availability, some variables (such as micro-level enterprise environmental behaviors) have not been included in the model, potentially affecting the comprehensiveness of the analysis. It is difficult to obtain data on specific environmental measures and waste disposal methods in enterprise production processes, making it impossible to deeply analyze the trade-environment relationship at the enterprise level. For example, the varying environmental management levels of small and medium-sized enterprises and the impacts of their differences in environmental technology application and pollution control investment on trade and the environment have not been fully studied.

2. Inadequate Portrayal of Dynamic Mechanisms

Although a dynamic panel model was used to reveal the long-term relationships between variables, the analysis of short-term dynamic adjustment mechanisms in the interaction between trade liberalization and environmental quality, as well as the time-lag effects of policy shocks, is insufficient, failing to fully reflect the complex feedback

processes in the real economy. For example, when the government introduces new environmental policies, enterprises need time to adjust production technologies and business strategies, but how the trade-environment relationship changes during this period has not been thoroughly analyzed in this study. Additionally, the short-term dynamic impacts of unexpected events in the trade liberalization process, such as the global financial crisis and trade frictions, on environmental quality have not been fully explored. After the 2008 global financial crisis, Chinese export enterprises faced issues such as reduced orders and excess production capacity, with some enterprises relaxing environmental management to reduce costs, causing short-term negative impacts on the environment, but such dynamic changes were not deeply characterized in the study.

3. Lack of International Comparative Research

The research is primarily based on China's national conditions, lacking horizontal comparisons with other developing or developed countries, making it difficult to extract universal laws and special experiences in balancing trade and the environment from a broader perspective. Countries differ in economic development levels, industrial structures, and policy systems, and their approaches and experiences in handling trade-environment relationships vary. For example, the EU has accumulated rich experience in green transformation through policy tools such as carbon trading markets and eco-labeling systems, while Southeast Asian countries face similar environmental issues to China during industrial relocation. However, this study did not carry out such comparative analyses, limiting the generalizability of research conclusions and preventing the extraction of more useful practices from international experiences to improve China's policy system.

4. Insufficient Forward-Looking Policy Simulation

Policy recommendations are mostly based on historical data and current situation analyses, lacking systematic predictions and evaluations of potential impacts brought by emerging trade models (such as digital trade), technological changes (such as artificial intelligence and blockchain), and global governance pattern evolutions. With rapid technological development and global economic restructuring, new trade models like digital trade and cross-border e-commerce are booming, while technologies such as AI and

blockchain are increasingly applied in trade and environmental fields, and global environmental governance patterns are undergoing profound changes. For example, the development of digital trade has led to frequent cross-border data flows, highlighting environmental issues such as data center energy consumption and electronic waste disposal. While AI applications in environmental monitoring improve efficiency, algorithmic biases may lead to flawed environmental decisions. How these new trends and changes will impact the relationship between international trade liberalization and environmental protection has not been sufficiently analyzed in this study, resulting in policy recommendations with limited pertinence and adaptability.

Future Research Prospects

To address the above limitations, future research can be carried out in the following directions:

1. Expanding Research Dimensions

Incorporate multi-source heterogeneous data such as satellite remote sensing data and enterprise environmental information disclosure data to construct multi-dimensional environmental indicator systems covering atmosphere, water, soil, and biodiversity. Satellite remote sensing data can provide real-time monitoring of air pollution and vegetation coverage, offering more accurate data support for environmental quality assessments. Enterprise environmental information disclosure data can reflect micro-level enterprise environmental behaviors, helping to deeply analyze enterprises' environmental decisions in trade activities. Meanwhile, combined with global value chain data, deeply analyze the indirect environmental impacts of intermediate goods trade and service trade. For example, study the environmental impacts of raw material production and transportation links in intermediate goods trade, as well as the role of service trade (such as financial services and information technology services) in promoting green industrial development. In the financial services sector, how the innovation and promotion of green financial products guide capital flows to environmental protection industries and thus influence trade-environment relationships is worthy of further study.

2. Deepening Dynamic Analysis

Use methods such as structural vector autoregression (SVAR) models and machine

learning algorithms to further explore the dynamic causal relationships between trade liberalization and environmental quality, quantify the transmission paths and impact intensities of policy shocks, and provide more accurate time-window predictions for policy-making. SVAR models can analyze the dynamic interactions between trade liberalization and environmental quality variables, capturing immediate and long-term effects between variables. Machine learning algorithms can handle complex non-linear relationships and uncover hidden patterns in data. For example, simulate how variables such as trade scale, industrial structure, and environmental quality change over different time periods after the introduction of different environmental policies, providing policy-makers with references on when to introduce policies and how to determine policy intensity. At the same time, policy simulation models can be built to analyze the short-term and long-term impacts of unexpected events (such as trade wars and pandemics) on trade-environment relationships and formulate advance response strategies.

3. Strengthening International Comparisons

Select typical countries or regions (such as Southeast Asian countries undertaking industrial relocation and EU economies undergoing green transformation) to carry out cross-national comparative studies, summarizing lessons from different institutional and developmental stage experiences in balancing trade and the environment, and providing international references for China's policy optimization. Through comparative analysis of environmental regulation policies, green technology innovation incentive mechanisms, and trade structure adjustment strategies in different countries, identify applicable experiences suitable for China's national conditions. For example, study the EU's successful experiences in promoting green industrial development and formulating strict environmental standards, as well as the lessons learned from Southeast Asian countries' environmental issues during industrial relocation, to provide references for China's policy-making. Meanwhile, international cooperative research projects can be carried out to jointly address new global trade-environment governance issues and challenges, enhancing China's voice in international environmental governance.

4. Exploring Frontier Issues

Focus on frontier fields such as the integration of digital trade rules and

environmental clauses, carbon border adjustment mechanisms in the context of climate change, and international cooperation networks for green technological innovation, conducting forward-looking research to help China gain the initiative in global green governance. With the rapid development of digital trade, how to integrate environmental clauses into digital trade rules to promote green digital trade development; under the increasingly severe climate change situation, how China should respond to the impact of carbon border adjustment mechanisms on international trade; and how to strengthen international cooperation in green technological innovation to build a global green technology innovation network—these are all important topics requiring in-depth study in the future. For example, study the impact of carbon border adjustment mechanisms on China's steel, cement, and other export industries and propose corresponding countermeasures. Analyze how digital trade platforms can reduce environmental impacts through algorithm optimization and data management to promote green digital trade development.

Balancing international trade liberalization and environmental protection is not only an internal requirement for China's high-quality development but also a common mission for global sustainable development. Through a combination of theoretical and empirical research, this study has revealed the complexity and dynamic nature of their relationship, and the proposed policy recommendations provide feasible paths for promoting green open economic construction. In the future, with the continuous advancement of China's "dual carbon" goals and the profound transformation of global environmental governance systems, the coordinated development of trade and the environment will face more opportunities and challenges. This requires joint efforts from academia, policy circles, and enterprises to continuously explore theoretical innovation, policy practice, and technological breakthroughs, contributing wisdom and strength to building a modern economic system featuring harmonious coexistence between humanity and nature.

Meanwhile, research on trade liberalization and environmental protection is a continuously evolving field. With the emergence of new issues and phenomena, sustained in-depth research is needed to better adapt to the needs of era development and achieve coordinated and sustainable economic, social, and environmental development. In future

research, more attention should be paid to multidisciplinary integration, comprehensively using methods from economics, environmental science, data science, and other disciplines to deeply analyze the internal mechanisms of trade-environment relationships. Strengthen international cooperation and exchanges to jointly address global environmental issues and trade challenges, and promote global green development processes.

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