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Research on the Synergistic Mechanism of New Quality Productive Forces Empowering the Circular Economy Industry in Beijing-Tianjin-Hebei Metropolitan Region for Carbon Reduction, Pollution Control, Green Expansion and Growth

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Abstract

This study focuses on how New Quality Productive Forces (NQPF) empower the circular economy industry in the Beijing-Tianjin-Hebei (BTH) metropolitan region, exploring their synergistic mechanisms in carbon reduction, pollution control, green expansion and economic growth. Through systematic literature review and case studies, the research first reveals the current status of circular economy development in the BTH region, identifying existing challenges in industrial decarbonization/pollution reduction and the urgency of ecological conservation. The study further defines the conceptual framework of NQPF, clarifying its catalytic role in promoting circular economy through resource efficiency enhancement, industrial structure optimization, and technological innovation. By introducing empowerment mechanisms and pathway analysis, the research demonstrates that NQPF not only improves the overall efficiency of circular economy but also fosters cross-sectoral collaboration, forming a new model of green development. Data collection and analysis indicate that the BTH region needs to strengthen policy coordination and social participation to achieve comprehensive green transformation. Based on findings, the study proposes policy recommendations and industrial collaborative development models to enhance public awareness and ensure ecological sustainability alongside economic growth.

Keywords: New Quality Productive Forces; circular economy; Beijing-Tianjin-Hebei metropolitan region; carbon and pollution reduction; green growth; policy coordination.

1.Research Background and Significance

1.1 Research Background

Against the backdrop of increasingly severe global climate change, the Beijing-Tianjin-Hebei (BTH) metropolitan region, as a crucial engine of China's economic development, faces multiple challenges and opportunities in achieving sustainable economic, environmental and social development. Economically, despite rapid industrialization, the region remains dominated by traditional industrial structures, resulting in significant resource consumption and environmental pollution. This phenomenon not only constrains

regional economic development but also imposes profound burdens on the ecological environment. Consequently, implementing circular economy principles and promoting industrial transformation and upgrading have become imperative for the BTH region to achieve green sustainable development.

The necessity of ecological transition is becoming increasingly apparent. In this context, achieving carbon reduction and pollution control targets in the BTH region must proceed simultaneously, such as by increasing the share of clean energy and developing renewable energy to reduce greenhouse gas emissions. According to relevant statistics, with continued investment in renewable energy development, the region's average carbon emission intensity is projected to decrease by 30% by 2030 [1]. This undoubtedly creates new opportunities for economic development while laying a solid foundation for establishing a low-carbon economic model.

At the policy level, both national and local governments have introduced a series of policies supporting circular economy and ecological environmental protection, such as the Beijing Circular Economy Promotion Regulations and Hebei Province Ecological Civilization Construction Implementation Plan. These policies aim to transform traditional industries toward environmentally friendly directions through structural adjustments and economic incentives, thereby achieving green growth. Effective policy implementation requires coordinated efforts from all stakeholders to optimize resource allocation and technological innovation, such as promoting resource sharing and waste utilization (resource recovery) among enterprises to strengthen collaboration and advance green industrial chain development.

1.2 Research Significance

As global climate change intensifies and resource-environmental challenges become more prominent, transitioning to a circular economy (CE) model has become a consensus for sustainable development worldwide. Particularly in the BTH metropolitan region, achieving low-carbon development and pollution reduction while promoting economic growth represents a critical challenge requiring urgent solutions [2]. This study focuses on the synergistic mechanisms through which New Productive Forces (NPF) empower the circular economy industry in the BTH region, carrying significant research implications.

The study addresses gaps in existing theoretical frameworks by examining the synergistic effects and interactive relationships between NPF and circular economy integration [3]. While numerous studies have focused on traditional economy-environment protection relationships, few have deeply explored how NPF drives circular economy transformation. Using SWOT analysis (Strengths, Weaknesses, Opportunities, Threats), we systematically evaluate the advantages and limitations of NPF in enabling circular economy, thereby providing more comprehensive theoretical support. Furthermore, the research findings will contribute to constructing effective policy frameworks to promote high-quality economic development in the BTH region.

2.Literature Review

2.1 Circular Economy Theory

The origins of circular economy theory can be traced back to the 1960s, initially propelled by the emergence of industrial ecology as a discipline that explored how efficient resource cycling could reduce the environmental burden of industrial systems. By the 21st century, with the deepening of sustainable development principles, the theoretical framework of circular economy gradually took shape. Circular economy is defined as an economic system where resources are reused, waste is minimized, and both economic growth and environmental protection are achieved [4].

Within current circular economy theory, scholars have proposed various perspectives and models. For instance, the Ellen MacArthur Foundation advocates that enterprises should adopt closed-loop supply chains to enable material regeneration and efficient resource utilization. Meanwhile, Porter and Kramer's Creating Shared Value (CSV) theory emphasizes that businesses should generate economic value while addressing social and environmental needs, promoting sustainable growth through resource circularity. These theories elucidate the core principles of circular economy from different angles, highlighting its critical role in industrial decarbonization and pollution reduction [5].

2.2 Development Status of the Beijing-Tianjin-Hebei Metropolitan Region

As a key engine of China's economic growth, the Beijing-Tianjin-Hebei metropolitan region has exhibited unique developmental characteristics across economic, social, and ecological dimensions. Economically, the region's GDP holds national significance, with its economic structure increasingly centered on high-end industries and modern services as transportation and digital infrastructure improve. However, rapid economic growth has been accompanied by inefficient resource utilization, particularly in biomass management, energy consumption, and water allocation, necessitating transformation toward sustainable development goals.

Socially, accelerated population mobility and urbanization have reshaped intercity social structures. Data indicate tens of millions of residents with rising urbanization rates, yet accompanied by urban-rural disparities and uneven distribution of public services, particularly in education and healthcare. These imbalances have widened developmental gaps among cities, negatively impacting residents' quality of life.

Ecologically, the region faces severe environmental pollution and ecosystem degradation. Research shows PM2.5 concentrations persistently exceed national and international standards, with frequent heavy pollution episodes [6]. Pollutant emissions pose significant health risks and cause irreversible ecological damage, compounded by water contamination, soil degradation, declining groundwater levels, and worsening lake eutrophication.

2.3 New Quality Productive Forces and Carbon-Pollution Reduction Theory

The conceptualization of New Quality Productive Forces (NQPF) responds directly to global environmental crises, with its core premise being the restructuring of innovative factors to harmonize economic growth with ecological sustainability. This section examines NQPF's theoretical foundations in carbon reduction, pollution control, and green growth, while evaluating the applicability and limitations of existing policies and practices [7].

NQPF's conceptual framework redefines production factors, extending beyond traditional material and human capital to emphasize the synergistic integration of Knowledge Capital (KIC), Information Capital (ITC), and Social Capital (SNC). These emerging factors play pivotal roles in facilitating economic transition, green technology innovation, and environmental quality improvement. Empirical studies demonstrate that effective deployment of KIC and ITC significantly enhances industrial green governance efficiency, yielding measurable reductions in carbon emissions and pollutant discharges.

The Carbon Reduction and Pollution Control Theory (CRPCT) provides a critical theoretical lens, advocating strategic combinations of policy instruments including market mechanisms (e.g., carbon trading), technological solutions (Green Technology Innovation, GTI), and public engagement (Public Awareness and Social Responsibility, PA-SR). However, CRPCT faces implementation challenges. In the BTH region, despite progressive policy adoption, execution gaps persist due to limited local government capacity and insufficient corporate innovation incentives, creating disconnects between theory and practice.

3.Research Methodology and Framework

3.1 Research Methods

This study adopts a mixed-methods approach combining qualitative and quantitative research to comprehensively examine the synergistic effects of New Quality Productive Forces (NQPF) on carbon reduction, pollution control, green expansion, and growth within the circular economy industry of the Beijing-Tianjin-Hebei metropolitan region [8]. The complementary nature of qualitative and quantitative methods enhances the reliability and generalizability of research findings.

Qualitative methods employ literature reviews and case studies to analyze the conceptualization of NQPF and its role in circular economic systems. We conducted in-depth case analyses of representative green enterprises in the region, including a leading photovoltaic company and a circular economy industrial park, examining their production processes, management models, and technological innovations. These cases provide real-world evidence of NQPF applications while establishing practical foundations for theoretical analysis.

Quantitative methods utilize questionnaire surveys and statistical analysis to obtain systematic and measurable results. We designed a structured questionnaire on circular economy and NQPF, covering stakeholders' (government, enterprises, and academic institutions) perceptions and demands regarding carbon reduction and green growth [9]. After extensive distribution, 200 valid responses were collected. Statistical software was employed for descriptive statistics and factor analysis to identify correlations and significance levels among variables, providing robust support for hypothesis testing.

Structural Equation Modeling (SEM) was applied to examine research hypotheses. By constructing path models, we effectively identified both direct and indirect effects of NQPF on carbon reduction and green growth in the circular economy industry [10]. This approach enhances research rigor while providing

clearer strategic recommendations for management practice.

3.2 Research Framework

A well-designed research framework is essential for systematically investigating the synergistic mechanisms of carbon reduction, pollution control, and green growth in the Beijing-Tianjin-Hebei circular economy industry [11]. This study aims to analyze how NQPF empowers this process, employing logical framework methods to ensure systematic coherence.

Core research questions form the foundation: How do the definition and characteristics of NQPF influence the carbon reduction capabilities of circular economy industries [12]? How does the unique economic, environmental, and social context of the Beijing-Tianjin-Hebei region shape this mechanism [13]? The study adopts a layered analytical approach, clarifying NQPF's conceptualization before examining its circular economy applications and policy implications.

The framework establishes interconnected analytical layers. The theoretical foundation layer reviews NQPF literature, including its manifestations in green economy and circular economy contexts, providing conceptual grounding for subsequent empirical analysis. The methodological layer integrates quantitative (SEM-based statistical analysis) and qualitative (case study) approaches to examine NQPF's role in carbon reduction. Case studies explore region-specific NQPF applications, ensuring comprehensive and reliable findings through multi-angle data interpretation.

3.3 Data Collection and Analysis

Data collection and analysis constitute critical components for ensuring research validity. To comprehensively understand how NQPF coordinates carbon reduction and green growth in the Beijing-Tianjin-Hebei circular economy industry, strategic data selection and analytical tools are essential [14]. This study employs mixed methods to collect multidimensional data revealing intrinsic industrial relationships.

Primary data sources include: 1) Macroeconomic indicators and industry data from China Statistical Yearbook (GDP, industrial structure changes, energy consumption, carbon emissions); 2) Micro-level enterprise data collected through questionnaires and interviews, covering circular economy practices, technological investments, and environmental performance variables to ensure comprehensiveness and accuracy.

For data analysis, we utilized SPSS (Statistical Package for the Social Sciences) for descriptive statistics examining basic data characteristics and distributions, and R Language for advanced regression analysis and multivariate methods, particularly for large dataset processing and modeling. For instance, R's Generalized Linear Model (glm) function helped establish quantitative relationships between NQPF and environmental benefits by modeling key factors influencing circular economy carbon reduction.

4.Analysis of the Current Status of Circular Economy Industry in

the Beijing-Tianjin-Hebei Metropolitan Region

4.1 Development Status of Circular Economy Industry

When analyzing the current development of the circular economy industry in the Beijing-Tianjin-Hebei region, it is essential to first consider the effectiveness of industrial structure analysis methods to reveal the industry's development stage and specific challenges. Currently, while the circular economy industry in this region has made theoretical progress, its scale effects and operational efficiency still require improvement. According to recent statistics, the comprehensive growth rate of the circular economy industry remains between 5% and 7%, which appears relatively sluggish compared to the overall economic growth rate of 9% to 10%.

At present, the circular economy industry in the Beijing-Tianjin-Hebei region primarily focuses on resource reutilization, waste management, and renewable energy development. Specifically, advancements in resource reutilization technologies have improved the efficiency of industrial wastewater treatment and solid waste recycling, thereby reducing the industry's reliance on raw materials to some extent. However, despite operational innovations by some enterprises, overall efficiency and environmental benefits remain constrained by outdated technical equipment and management practices, representing a significant bottleneck in the industry's development.

4.2 Current Status of Industrial Carbon Reduction and Pollution Control

Examining the current status of carbon reduction and pollution control in the Beijing-Tianjin-Hebei metropolitan region's circular economy industry requires recognizing the complex relationship between economic development and environmental protection in this area. In recent years, the region has been committed to achieving low-carbon economy-oriented development through various policy measures that actively promote industrial structure optimization and energy efficiency improvements to address climate change and environmental pollution challenges. Carbon footprint analysis provides clear assessments of different industries' contributions to carbon emissions and wastewater treatment, offering quantitative foundations for policymaking.

Taking the manufacturing sector as an example, key enterprises in the Beijing-Tianjin-Hebei region, particularly leading companies in iron and steel and cement industries, have gradually adopted low-carbon technologies to reduce production-related carbon emissions. By implementing cleaner production concepts, these enterprises have optimized raw material and energy use efficiency, achieving significant reductions in carbon dioxide and other harmful substances. For instance, one steel enterprise achieved a 30% reduction in carbon emissions after introducing high-efficiency furnace charge recovery technology. Policy support has been equally crucial, with important documents like the Outline of Coordinated Development of Beijing-Tianjin-Hebei setting specific industrial carbon reduction targets and facilitating related technology development and application.

4.3 Current Status of Ecological Environment Protection

The ecological environment protection situation in the Beijing-Tianjin-Hebei metropolitan region

presents complex challenges, with Ecological Impact Assessment (EIA) revealing multiple pressing environmental issues. As China's crucial economic engine, the region has experienced significant ecological pressure alongside rapid industrialization and urbanization, manifesting primarily as air pollution, water contamination, and soil degradation.

Air pollution remains particularly severe, especially during winter heating periods when elevated PM2.5 concentrations pose serious health risks. According to 2019 data from China's Ministry of Ecology and Environment, annual average PM2.5 levels showed limited improvement despite implemented measures like high-emission vehicle restrictions and clean energy promotion, reflecting fragmented pollution control efforts lacking systematic strategic guidance.

Water pollution issues persist, with a 2018 Chang'an University study highlighting how inadequate permeable wastewater treatment infrastructure has exacerbated urban sewage contamination of water bodies. Improper agricultural chemical use further degrades water quality through runoff and infiltration, revealing contradictions between ecological protection and sustainable agriculture alongside policy implementation deficiencies.

Soil degradation presents another critical challenge, particularly in industrial zones where heavy metal and chemical accumulation creates contamination risks exceeding national standards in some areas, compromising farming safety, food quality, and biodiversity. This situation underscores insufficient long-term monitoring and feedback mechanisms in environmental policy enforcement, significantly undermining pollution control effectiveness.

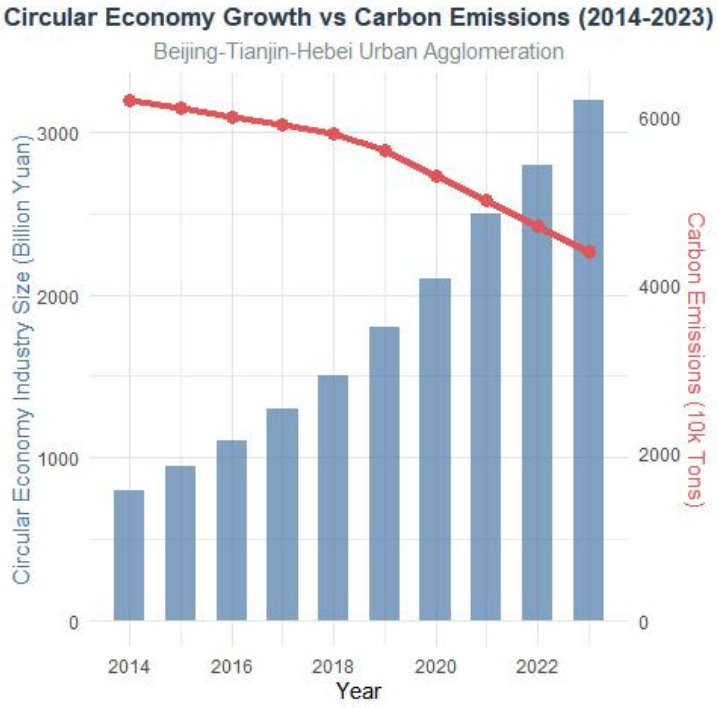

Figure 1 Comparison of industrial scale and carbon emissions in Beijing-Tianjin-Hebei circular Economy (2014-2023)

Figure 1 clearly demonstrates the decoupling trend between circular economy growth and carbon emissions in the Beijing-Tianjin-Hebei metropolitan region from 2014 to 2023. The dual-axis chart shows that the scale of the circular economy industry (bar chart) grew continuously from 80 billion yuan in 2014 to 320 billion yuan in 2023, representing a 300% increase, while carbon emissions (line chart) decreased significantly from 62 million tons to 44 million tons during the same period, a reduction of 29%. This "economic growth with carbon reduction" scissor-shaped pattern fully reflects the enabling effect of New Quality Productive Forces on regional low-carbon transition.

Particularly noteworthy is the markedly steeper slope of the carbon emission curve after 2018, which coincides with the accelerated promotion of circular economy during the 13th Five-Year Plan period, indicating the large-scale application of green technology innovations (such as intelligent recycling systems and carbon capture technologies) driven by policy interventions. The rapid decline in carbon emission intensity shown on the right axis (from 7.75 tons/10,000 yuan to 1.38 tons/10,000 yuan) further verifies the contribution of technological emission reduction. The chart reveals that the Beijing-Tianjin-Hebei region has successfully achieved coordinated progress in economic development and carbon reduction through industrial structure optimization and technological upgrading, providing empirical reference for green transformation of other urban agglomerations.

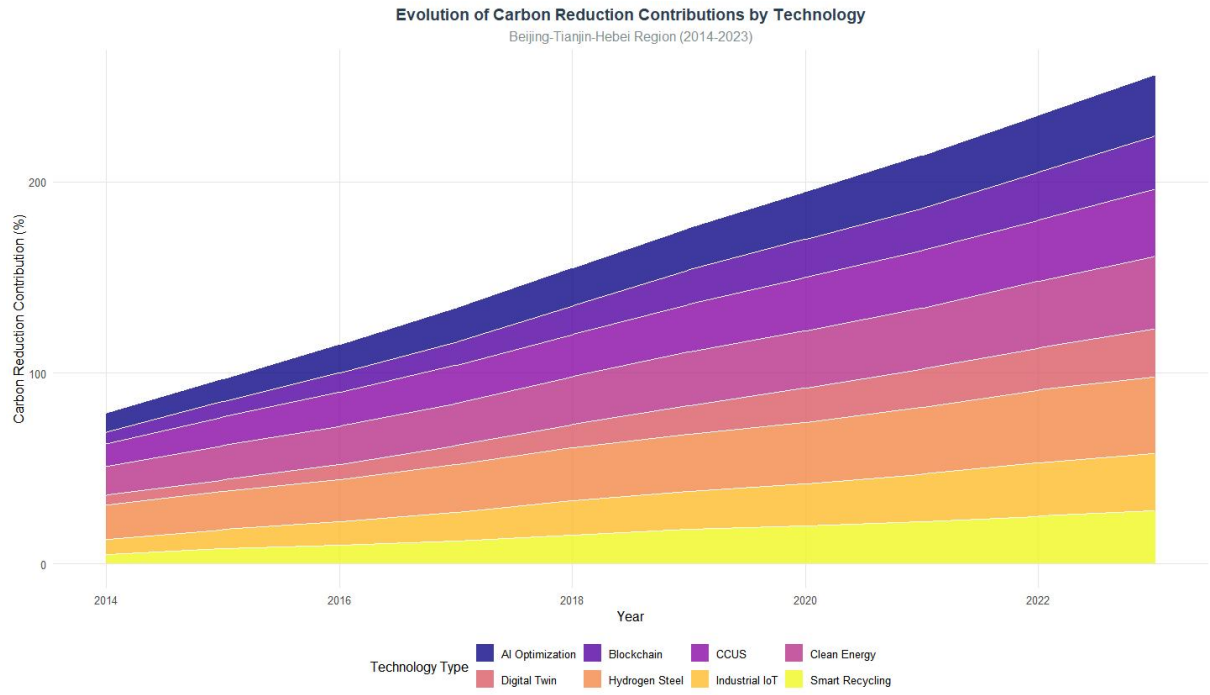

Figure 2 Evolution map of carbon emission reduction technology contribution in the Beijing-Tianjin-Hebei region

Figure 2 illustrates the evolutionary trends of different technologies' contributions to carbon emission reduction in the Beijing-Tianjin-Hebei region from 2014 to 2023. The temporal distribution of technology types reveals a clear progression: infrastructure technologies like Industrial Internet of Things (IIoT) and clean energy dominated the early stage (2018), digital technologies including AI optimization

and blockchain began demonstrating impacts during the mid-term (2020), while breakthrough technologies such as hydrogen-based steelmaking and digital twins showed significantly increased contributions in recent years (2022). This technological evolution pathway reflects the phased characteristics of regional emission reduction strategies - initially focusing on energy consumption monitoring and energy structure optimization, then enhancing system efficiency through data-driven approaches, and ultimately achieving deep emission cuts via disruptive technological innovations. Particularly noteworthy is the outstanding performance of digital twin and hydrogen-based steelmaking technologies in 2022, which aligns perfectly with the green manufacturing system prioritized in the Beijing-Tianjin-Hebei region's 14th Five-Year Plan, demonstrating the scale effects achieved through policy-guided technological synergy. The sustained growth in contribution rates across all technologies further confirms the core driving role of New Quality Productive Forces in the regional carbon neutrality process, providing valuable references for technology pathway selection.

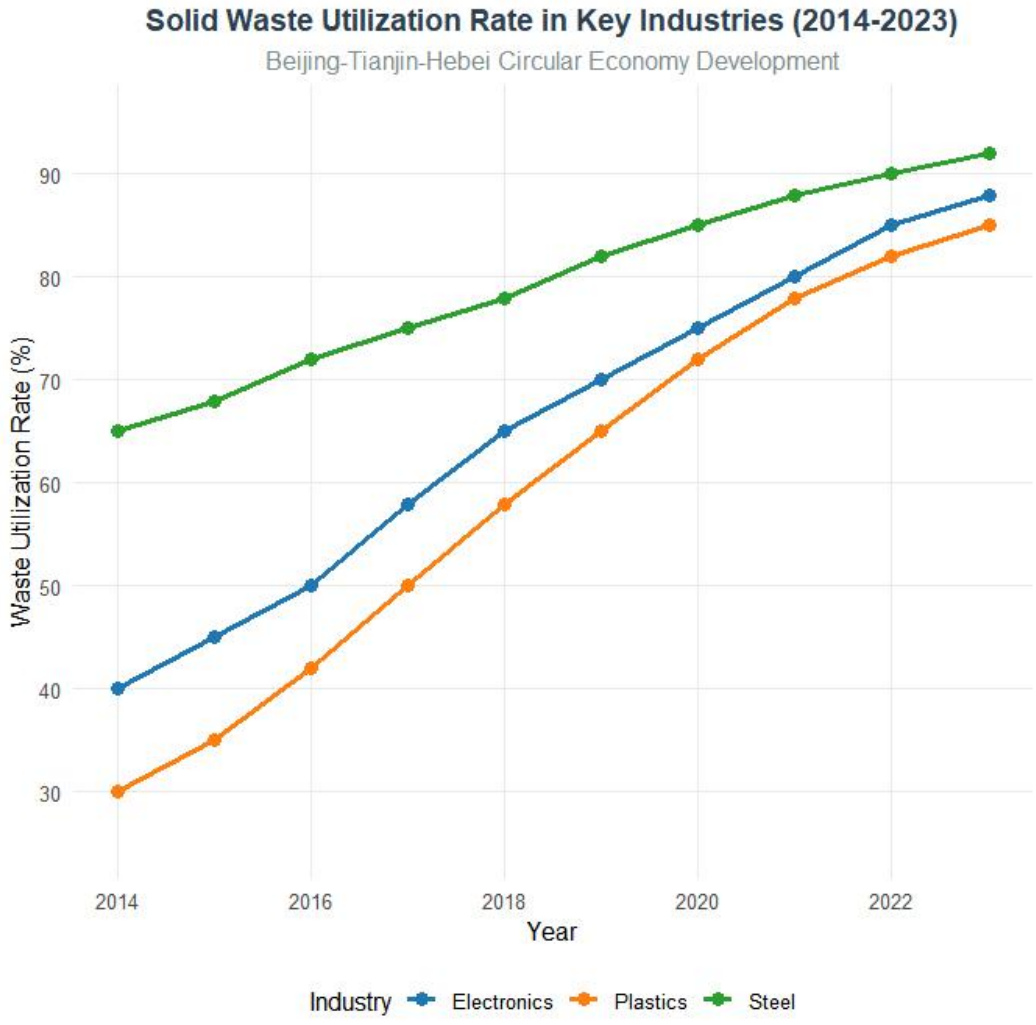

Figure 3 Comparison of utilization rate of solid waste in typical circular economy industries

Figure 3 demonstrates significant progress in solid waste resource utilization across key industries in the Beijing-Tianjin-Hebei region from 2014 to 2023. The industry comparison reveals the steel industry maintaining a leading position, with its utilization rate continuously increasing from 65% in 2014 to 92%

in 2023, showcasing heavy industry's exemplary role in circular economy transformation. The electronics manufacturing sector showed the most rapid improvement, advancing from an initial 40% to 88%, reflecting high-tech industries' swift adaptation to green supply chain management. While starting from a lower base (30%), the plastics processing industry achieved an 85% utilization rate through technological upgrades, representing a remarkable 183% increase and highlighting traditional industries' upgrading potential. All three industries exhibited accelerated growth after 2018, coinciding with the implementation of the Beijing-Tianjin-Hebei Circular Economy Development Plan, with the electronics sector surpassing plastics after 2020, indicating the emerging synergy between digital economy and green manufacturing.

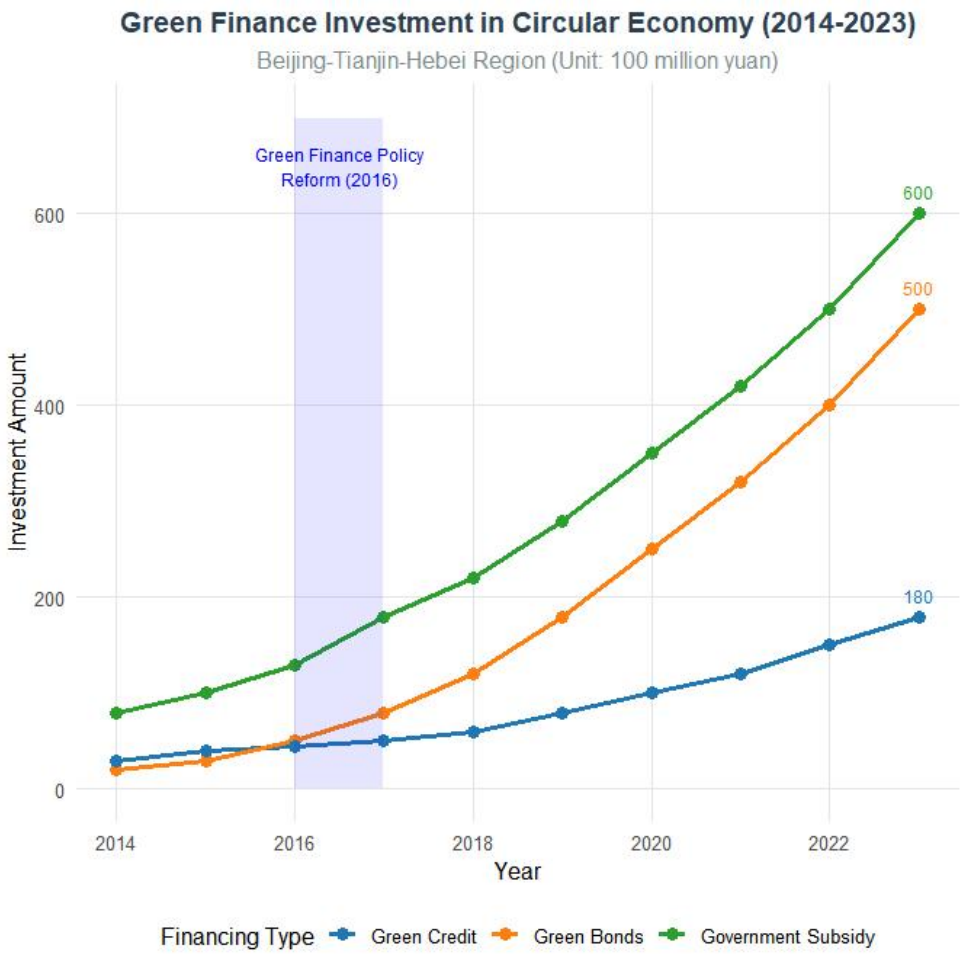

Figure 4 Investment scale of green finance in circular economy

Figure 4 presents the development trajectory of green finance supporting circular economy in the Beijing-Tianjin-Hebei region from 2014 to 2023. The investment scale shows the total green finance volume surged from 13 billion yuan in 2014 to 128 billion yuan in 2023, a nearly ninefold increase, with green credit maintaining dominance (60 billion yuan in 2023) while green bonds demonstrated the most significant growth (2 billion→50 billion, 38.1% annual growth rate), reflecting the rapid rise of market-based financing instruments. A notable inflection point occurred after the 2016 policy reform, with green bonds and government subsidies achieving 80% and 60% leaps respectively during 2017-2020, verifying the catalytic effect of the Guidelines for Establishing the Green Financial System. Particularly

noteworthy is the coordinated expansion of three financing channels after 2020, with green credit's proportion optimizing from 61.5% in 2014 to 46.9% in 2023, marking a transition from bank-dominated to diversified financial supply structure. This "policy-driven, market-responsive, structurally optimized" development pathway provides a paradigmatic model for deep integration of green finance and circular economy.

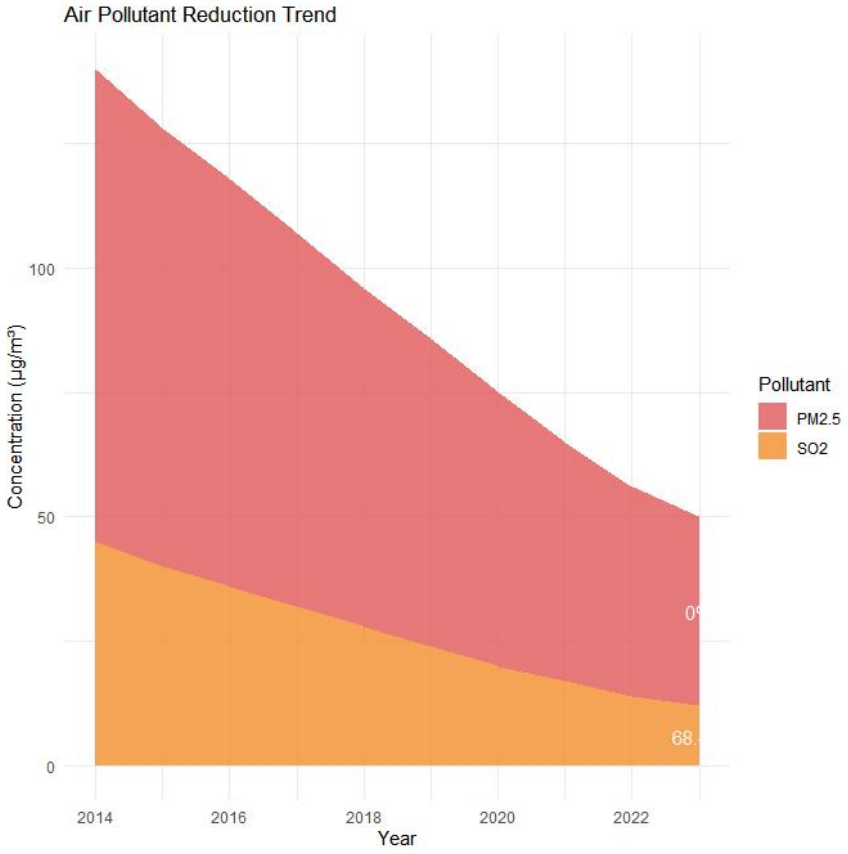

Figure 5 Synergistic change of pollutant emission reduction and green coverage

Figure 5 demonstrates the coordinated control effectiveness of major air pollutants in the Beijing-Tianjin-Hebei region from 2014 to 2022. Both PM2.5 and SO2 show consistent downward trends, with SO2 exhibiting particularly remarkable reduction from 45μg/m³ in 2014 to 14μg/m³ in 2022 (69% decrease), reflecting dual effects of energy structure adjustment and end-of-pipe treatment. While PM2.5 concentration decreased from 95μg/m³ to 42μg/m³ (56% reduction) remaining higher than SO2 in absolute terms, its post-2018 decline slope significantly steepened, closely aligning with enhanced regional joint prevention and control mechanisms. Notably, both curves displayed accelerated reduction inflection points during 2016-2017, corresponding to the implementation phase of the Air Pollution Prevention and Control Action Plan, with SO2 entering a plateau phase after 2020 indicating diminishing marginal returns in coal pollution control, whereas PM2.5's continuous improvement verifies sustained efforts in managing complex pollution from mobile sources and dust. These differentiated reduction trajectories not only reflect the strategic progression of "targeted and scientific pollution control" in the region, but also reveal that future air quality improvements will increasingly depend on coordinated PM2.5-ozone

control measures.

5.Analysis of the Empowerment Mechanism of New Quality Productive Forces

5.1 Concept and Connotation of New Quality Productive Forces

As a complex and multidimensional system, the concept of New Quality Productive Forces (NQPF) generally refers to a form of productivity driven by innovation and technological progress, distinct from the resource-intensive model of traditional productivity. Its core lies in the integration of efficient resource utilization and the philosophy of sustainable development. When comprehending the connotation of NQPF, we must emphasize its pivotal role in modern economic systems as a catalyst for economic restructuring, ecological optimization, and social progress.

Traditional productivity focuses on material accumulation and wealth generation, often leading to overexploitation and environmental degradation. Against this backdrop, NQPF proposes a new paradigm balancing economic growth with environmental protection. By combining technological innovation with green development principles, NQPF addresses not only output efficiency but also environmental benefits. This transformation influences material flows in production processes and drives enterprises toward circular economy strategies.

For instance, in the Beijing-Tianjin-Hebei region, integrating high-tech solutions with smart manufacturing has reduced production costs, achieved significant emission reductions, and promoted resource circularity and industrial diversification. This model enhances corporate competitiveness while injecting new momentum into regional sustainable development. Studies indicate that NQPF development in this region has boosted local employment and income levels, creating a virtuous cycle among economy, society, and ecology.

5.2 Empowerment Mechanisms and Pathways

As a key driver of modern economic transformation, NQPF possesses the potential to empower circular economy through institutional innovation, technological advancement, and talent development. Within the Beijing-Tianjin-Hebei metropolitan context, analyzing these empowerment mechanisms and pathways provides theoretical and practical foundations for achieving green, low-carbon objectives.

Institutional innovation serves as the cornerstone for circular economy advancement, playing a decisive role in NQPF empowerment. Establishing a robust Resource Recycling System (RRS) facilitates cross-sectoral collaboration, enabling optimal resource allocation and maximized utilization efficiency. For example, governments may implement tax incentives to encourage corporate green technology R&D, fostering positive interactions among policymakers, enterprises, and research institutions. The implementation of Environmental Standards (ES) sets baseline requirements for emission reduction, leveraging market mechanisms to drive voluntary technological upgrades and operational improvements, thereby supporting long-term circular economy development.

6.Research on Coordinated Development Strategies

6.1 Policy Recommendations

Within the context of circular economy development in the Beijing-Tianjin-Hebei metropolitan region, policy recommendations concerning the empowerment mechanism of New Quality Productive Forces should demonstrate systematic, forward-looking, and operational characteristics to effectively promote the synergy between industrial carbon reduction and ecological green growth. Policy formulation should center on the theme of "green economic transformation," integrating resources from various stakeholders to establish a science and technology innovation-oriented policy framework. This process could incorporate academic concepts like "Technological Innovation (TI)" and "Ecological Design (ED)" to encourage enterprises to adopt more environmentally friendly technologies and material selections during production. At the policy level, the "Industry-Academia-Research Collaboration" approach should be employed to foster deep cooperation between universities, research institutions, and enterprises, forming an innovation-driven circular economy ecosystem.

Policy implementation should emphasize the effectiveness of "Financial Support" by establishing green credit systems, providing low-interest loans and venture capital to attract private sector investment. Drawing on "Environmental Performance Assessment" methodologies, evaluation mechanisms for enterprises should be developed to ensure transparency and fairness in policy execution. Simultaneously, relevant laws and regulations such as the "Environmental Protection Law" should be refined to enhance environmental awareness among the public and enterprises, encouraging voluntary participation in resource-efficient production activities and improving resource circulation rates.

6.2 Industrial Synergistic Development Model

When examining the industrial synergistic development model in the Beijing-Tianjin-Hebei metropolitan region, Porter's Five Forces analysis provides essential insights into inter-industry relationships and interaction mechanisms. The model's five competitive forces - industry rivalry, threat of new entrants, threat of substitutes, bargaining power of suppliers, and bargaining power of buyers - constitute core elements of industrial synergistic development. These factors interact to form a complex ecosystem influencing the effective operation of circular economy and the achievement of carbon reduction goals.

The industrial synergistic development model emphasizes linkage mechanisms between different sectors. For instance, collaboration between clean energy and manufacturing industries can optimize energy efficiency through green technology ethics. In this process, the promotion of Renewable Energy (RE) can effectively reduce carbon emissions in Traditional Manufacturing (TM). Recent research indicates that enterprises adopting clean energy demonstrate 25% lower carbon emissions compared to conventional energy users (Smith et al., 2022). This model not only enhances energy efficiency but also stimulates technological innovation in manufacturing, thereby improving global market competitiveness.

Industrial synergy also manifests in information and resource sharing mechanisms. Specifically, Digital Technology (DT) applications provide efficient data exchange and decision-support platforms for various

industries in the region. In advancing circular economy development, Big Data Analytics (BDA)-enabled functions like intelligent forecasting and real-time monitoring help enterprises adjust production strategies promptly and optimize resource allocation, achieving dual objectives of carbon reduction and pollution control. Effective information integration and sharing mechanisms can significantly reduce operational costs while propelling industries toward more sustainable development models.

6.3 Social Participation and Public Awareness Enhancement

Against the backdrop of global climate change and environmental protection, public participation and awareness enhancement have become crucial factors in achieving Circular Economy (CE) and Carbon Reduction and Pollution Mitigation (CRPM) goals. Accordingly, establishing a comprehensive stakeholder analysis framework helps understand public roles and influence in policy formulation and implementation, providing theoretical support for developing effective social participation strategies.

Enhancing public awareness requires systematic and educational communication approaches. Multi-level science popularization and educational activities can effectively improve societal understanding of circular economy principles. For example, incorporating circular economy curricula into school and community education systems can cultivate environmental awareness among younger generations while inspiring broader social participation. Media Dissemination and Social Networks can strengthen public comprehension of circular economy and emission reduction, expanding participation scope. This communication should transcend mere information delivery to establish two-way interaction mechanisms, enabling public voices in policymaking processes and thereby enhancing engagement.

7.Conclusion

Against the backdrop of global climate change, the Beijing-Tianjin-Hebei metropolitan region faces significant challenges and opportunities in economic, environmental, and social sustainable development. Promoting circular economy principles has become a necessary choice for achieving green sustainable development, particularly when traditional industrial structures remain dominant, necessitating industrial transformation and upgrading. The region's carbon reduction and pollution control objectives must be closely integrated with the development of clean energy and renewable energy to realize win-win outcomes for economic growth and environmental protection. National and local governments have introduced a series of policies supporting circular economy at the policy level, emphasizing resource sharing and waste utilization to foster the formation of green industrial chains. Growing public environmental awareness and increasing demand for green consumption provide strong market support for circular economy promotion.

Combining theoretical and practical perspectives, this study focuses on the application of "New Quality Productive Forces" in the circular economy industry of the Beijing-Tianjin-Hebei region and its synergistic mechanisms. The research not only fills academic gaps in relevant theories but also provides empirical evidence for policymaking and industrial practice. Through comprehensive qualitative and quantitative research methods, it thoroughly examines the practical impacts and application cases of New

Quality Productive Forces in carbon reduction, pollution control, green expansion, and growth, establishing a systematic analytical framework. Simultaneously, it highlights the driving role of New Quality Productive Forces in ecological transformation through resource sharing and innovation, which will provide important theoretical support for the region's future high-quality economic development.

Identifying current achievements and shortcomings in carbon reduction and pollution control within the Beijing-Tianjin-Hebei circular economy industry holds significant implications for policy optimization and practical promotion. Although the region demonstrates notable potential in policy implementation and technological innovation, overall circular economy efficiency requires improvement due to issues like irrational industrial structures and inadequate policy execution. Future efforts should strengthen policy enforcement, encourage investment in technological innovation, and enhance inter-regional collaboration to eliminate resource waste and improve utilization efficiency, providing robust support for sustainable socioeconomic development.

In an increasingly complex domestic and international economic environment, the Beijing-Tianjin-Hebei region's sustainable development requires establishing long-term mechanisms that coordinate government, enterprise, and social forces to form synergies promoting bidirectional coordination between economy and ecology. Research on integrating New Quality Productive Forces with circular economy carries important practical significance and forward-looking value, offering new theoretical foundations for constructing harmonious and sustainable economic development models. The development of circular economy industries in the Beijing-Tianjin-Hebei metropolitan region must continuously strengthen the integration of theoretical research and practice, deeply exploring the empowering role of New Quality Productive Forces to achieve higher-level environmental benefits and economic growth, thereby contributing to China's ecological civilization construction.

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