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Research on Low-Carbon Development Pathways for Modern Manufacturing in the Capital of China

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Abstract

This study systematically analyzes the current status, carbon emission characteristics, and key influencing factors of low-carbon development in Beijing's modern manufacturing sector. Using statistical data from 2015 to 2022, we constructed an evaluation index system for low-carbon development levels based on the entropy method. Combined with the STIRPAT model, the impact of variables such as energy efficiency and technological investment on carbon emissions was empirically tested. Findings reveal: Beijing's modern manufacturing sector has achieved significant overall improvement in low-carbon development, with the composite index increasing by 203.8% from 2015 to 2021. However, substantial inter-industry disparities exist, with the chemical raw materials and chemical products manufacturing sector showing the highest carbon emission intensity. Energy efficiency and technological investment serve as core drivers for emission reduction. The study proposes policy recommendations, including differentiated energy efficiency management, breakthroughs in core technologies, and industry-academia-research collaboration, providing theoretical support for the low-carbon transformation of manufacturing.

Keywords: Beijing, Modern manufacturing, Low-carbon development, STIRPAT model.

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1. Introduction and Literature Review

Since the 18th CPC National Congress, the Party and the state have placed high priority on manufacturing development. During his 2015 inspection tour of Beijing, the General Secretary explicitly outlined that manufacturing should advance toward "high-end, service-oriented, clustered, integrated, and low-carbon" development. The report of the 19th CPC National Congress proposed building a world-class advanced manufacturing cluster in the Beijing-Tianjin-Hebei region. [1] The 20th CPC National Congress made significant deployments, emphasizing that new industrialization holds a pivotal position in advancing Chinese modernization and developing new productive forces. As a vital pillar of the national economy, manufacturing is a key sector for transformation and upgrading in implementing the five development concepts, achieving modernization characterized by harmony between humanity and nature, and realizing the dual carbon goals.

As the capital, Beijing holds a unique position and bears significant responsibility in the development of the Beijing-Tianjin-Hebei cluster. It must play a leading and exemplary role in the low-carbon development of modern manufacturing, contributing to high-quality development and the nation's dual carbon goals. Guided by the principle of synergizing multiple objectives—including pollution reduction, carbon emission reduction, and high-end industrialization—a series of measures will be implemented. These include promoting technological innovation, optimizing industrial structures, and enhancing resource recycling. Such efforts will tightly integrate the high-quality development of the capital's modern manufacturing sector with low-carbon development, driving industrial structures toward high-end, intelligent, and green-low-carbon evolution [2]. This approach will provide robust support for building a modern economic system, enhance the capital's sustainable development capacity, and contribute to achieving Chinese-style modernization.

Existing research primarily explores low-carbon development in modern manufacturing through the following avenues: Regarding manufacturing low-carbon development, it quantitatively assesses the impact of internal and external environmental factors - such as digital transformation [3] and industrial clusters [4-5] - on manufacturing carbon emissions. Regarding modernization pathways, theoretical explorations have examined manufacturing production transformations like advanced manufacturing servitization [6-7], deep integration of the real and digital economies, and "green + smart manufacturing" [8], analyzing their mechanisms for driving high-end, intelligent, and green manufacturing transitions. However, existing research rarely examines Beijing's modern manufacturing low-carbon development from the perspective of synergistic modernization and decarbonization. Moreover, no studies have proposed specific policy pathways based on analyzing the low-carbon development levels of Beijing's modern manufacturing sub-sectors. This paper attempts to address these gaps.

2. Overview of Beijing's Modern Manufacturing Development

As China's political, economic, and cultural center, Beijing's low-carbon transformation in modern manufacturing holds exemplary and leading significance for guiding green development trends nationwide and globally. Based on the statistical scope of Beijing's modern manufacturing sector, this paper analyzes relevant data from 2015 onwards. It examines the modernization status of Beijing's manufacturing industry through four dimensions: scale structure and industry status, energy consumption structure and utilization efficiency, application of low-carbon technologies and processes, and policy regulations and standards systems.

2.1 Scale Structure and Industry Status of Modern Manufacturing in the Capital

2.1.1 Scale Growth and Structural Evolution

In terms of value-added output, Beijing's modern manufacturing sector grew from RMB 74.05 billion in 2015 to RMB 292.31 billion in 2021, representing a cumulative growth rate of nearly 300%. From 2015 to 2020, value-added demonstrated steady upward momentum. However, during the pandemic period of 2020-2021, the output value of the pharmaceutical manufacturing sector surged from 131.39 billion yuan in 2020 to 393.03 billion yuan in 2021. Following the pandemic, the pharmaceutical manufacturing sector cooled, contributing to a 221.8 billion yuan decline in Beijing's modern manufacturing value-added output, primarily driven by the pharmaceutical sector's contraction. The share of modern manufacturing in total output grew steadily from 2.98% in 2015 to 7.12% in 2021, though it showed a downward trend in 2022 while maintaining an overall growth rate of approximately 3%, as illustrated in Figure 1.

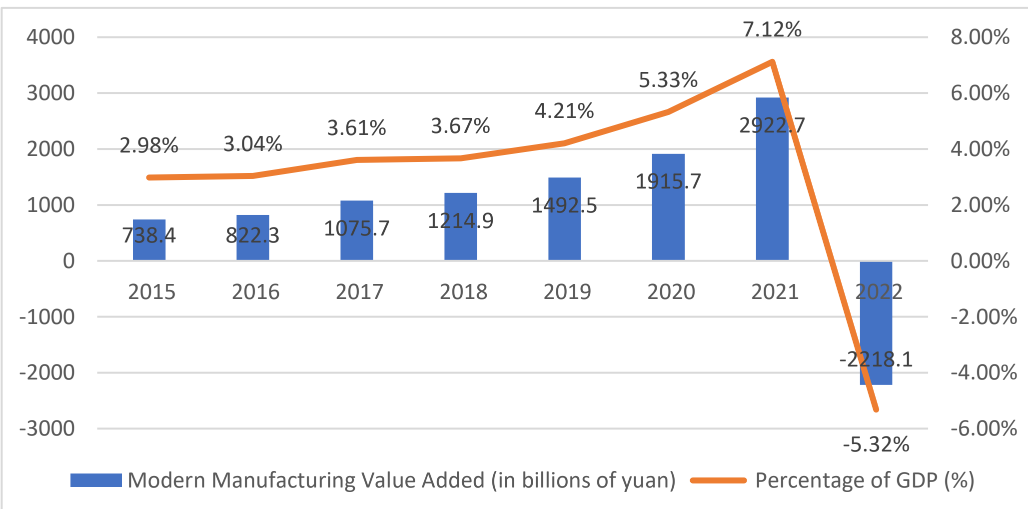


Figure 1: Changes in Beijing's Modern Manufacturing Value Added and Its Contribution to GDP, 2015-2022

As shown in Figure 2, the total output value of the communications equipment, computer, and other electronic equipment manufacturing sector, along with the automotive manufacturing sector, has consistently outperformed other industries over the long term. Among these, the electronics manufacturing sector has generally followed an upward trend, while the automotive manufacturing sector has shown a downward trend. The pharmaceutical manufacturing sector saw steady growth in total output value from 2015 to 2020. Affected by the pandemic, it achieved a leap in output value in 2021 before returning to normal levels in 2022. Industries such as general equipment manufacturing, specialized equipment manufacturing, and metal products manufacturing maintained relatively stable output values overall.

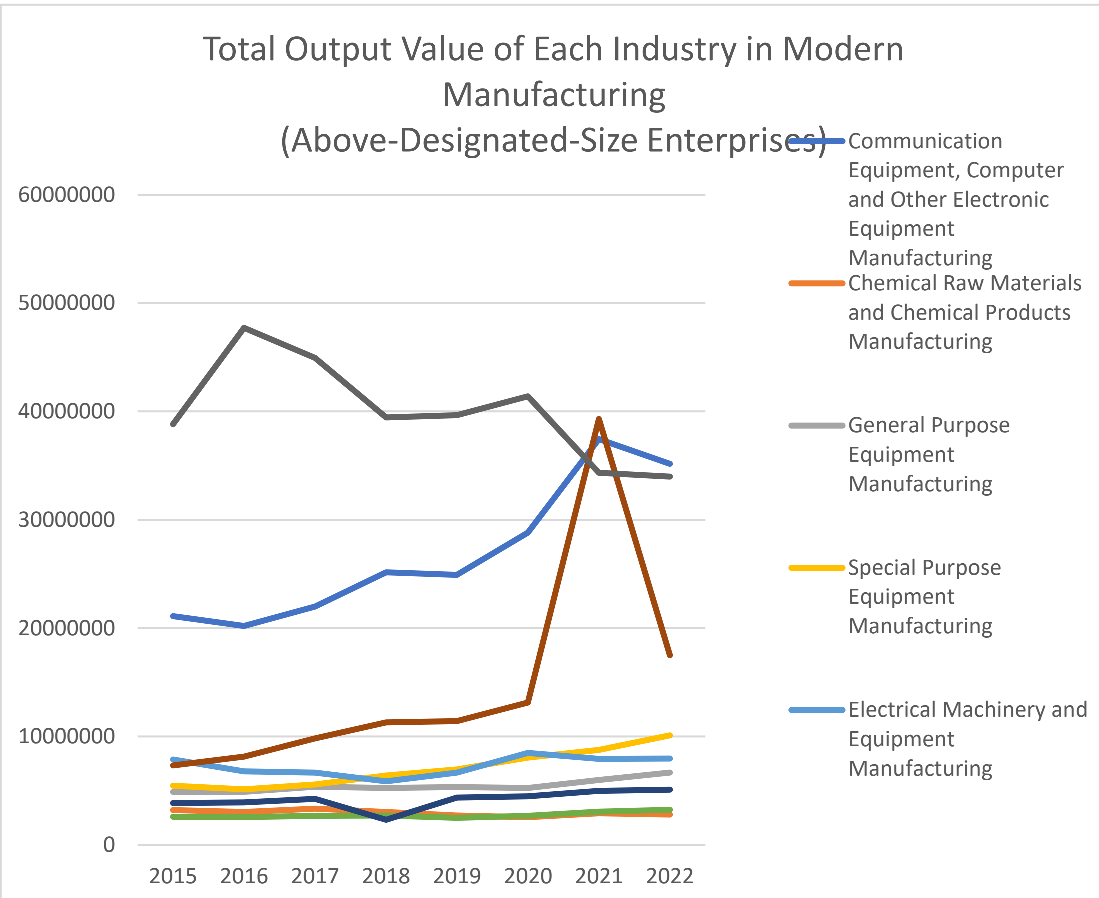


Figure 2: Changes in Total Output Value of Beijing's Modern Manufacturing Industries Above Designated Size(10k yuan), 2015-2022

The internal structure of modern manufacturing shows clear optimization (Figure 3). The share of value added from the electronic equipment manufacturing sector in modern manufacturing has steadily increased, rising from 25.4% in 2015 to 50% in 2020—accounting for half of modern manufacturing—before declining slightly after 2020. The share of pharmaceutical manufacturing rose steadily before 2020, climbing from 11.4% to 16.5%, then surged sharply to 89.5% in 2021. The share of transportation equipment manufacturing gradually decreased, falling from 42.8% in 2015 to -22.4% in 2021. This indicates that modern manufacturing has not only grown in total volume but has also undergone continuous optimization and upgrading in its internal structure. The status of the electronics sector has been continuously strengthened, while emerging industries represented by pharmaceutical manufacturing have achieved rapid development.

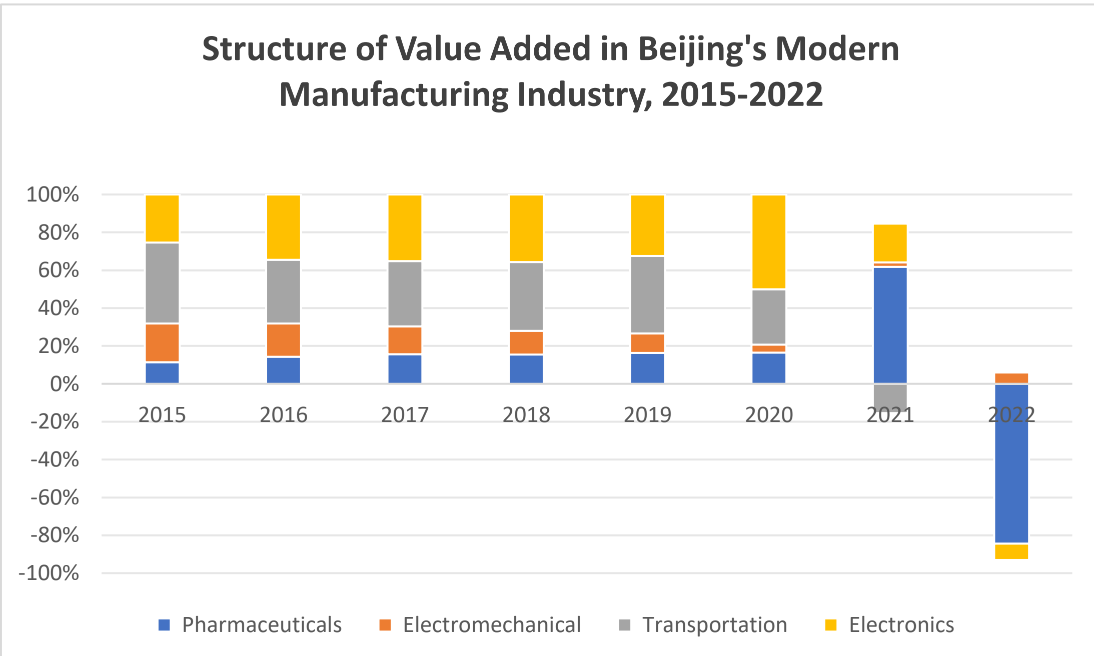


Figure 3: Beijing's Modern Manufacturing Value Added and Its Contribution to GDP, 2015-2022

2.1.2 Driving Effect of Strategic Emerging Industries

Strategic emerging industries represent the future direction of industrial development and play a core role in driving innovation and upgrading within modern manufacturing [9]. The State Council categorizes them into nine major fields, covering all sectors of modern manufacturing. In recent years, Beijing's strategic emerging industries have experienced rapid development and continuous expansion in scale. Their output value share of modern manufacturing increased from 34% in 2016 to 62% in 2022, effectively propelling the manufacturing sector toward high-end, low-carbon, and intelligent transformation. Through collaborative innovation across industrial chains, these industries have also fostered high-quality economic development.

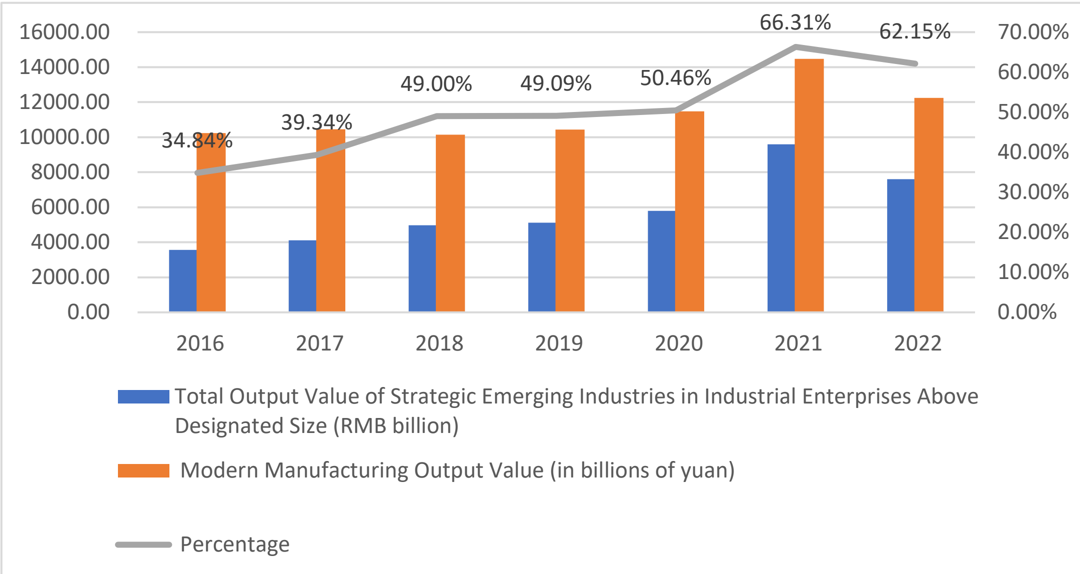


Figure 4: Total Output Value of Strategic Emerging Industries in Industrial Enterprises Above Designated Size and Their Share in Modern Manufacturing Output Value

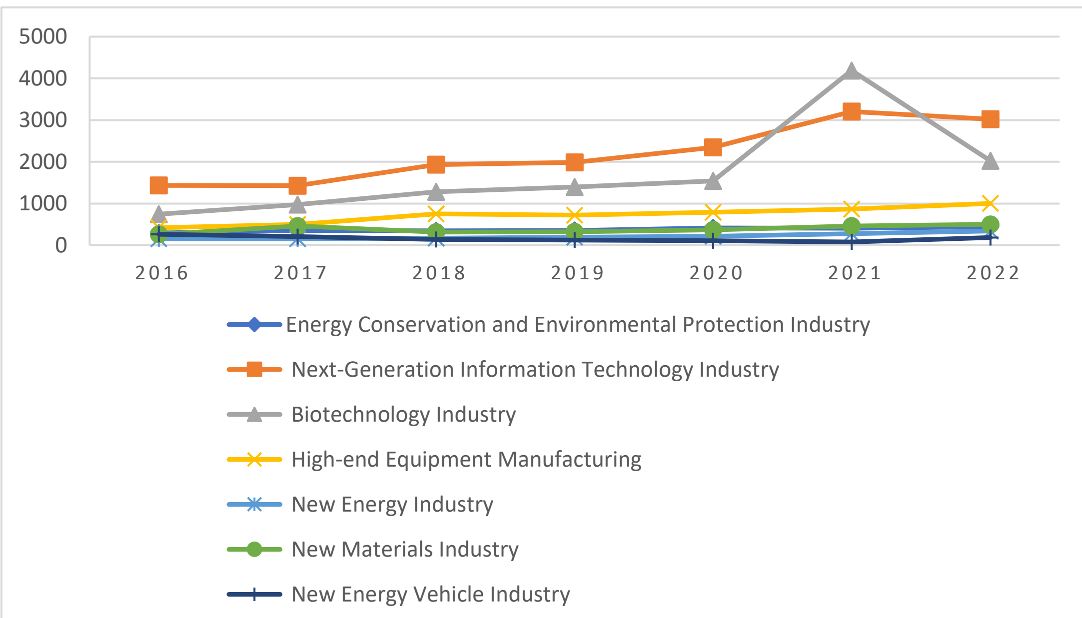


Figure 5: Output Value of Strategic Emerging Industries, 2016-2022

Among these, the top three sectors—next-generation information technology, biotechnology, and high-end equipment manufacturing—have made significant contributions: ① Next-generation information technology has substantially enhanced the technological sophistication of communications equipment, computer, and electronic equipment manufacturing. ② The biotechnology sector provides innovative momentum for pharmaceutical manufacturing. ③ High-end equipment manufacturing effectively elevates the intelligence level and production efficiency of specialized equipment. ④ Although sectors like new energy vehicles have a low share, they represent the green and low-carbon direction, offering technical support to related manufacturing industries while improving energy and resource efficiency and low-carbon levels.

2.1.3 The "Supply Chain Complementarity" Role of Specialized, Refined, Distinctive, and Innovative Enterprises

Specialized, refined, distinctive, and innovative SMEs play a pivotal role in enhancing industrial chain resilience by focusing on core technologies in niche sectors. Forty percent of their core technological products fill gaps in both domestic and international markets, while 50% are applied to address shortcomings in critical fields. [10]As of August 2024, Beijing has cultivated a cumulative total of 8,146 specialized, refined, distinctive, and innovative enterprises, including 697 national-level "Little Giant" enterprises—the highest number nationwide (Figure 6).

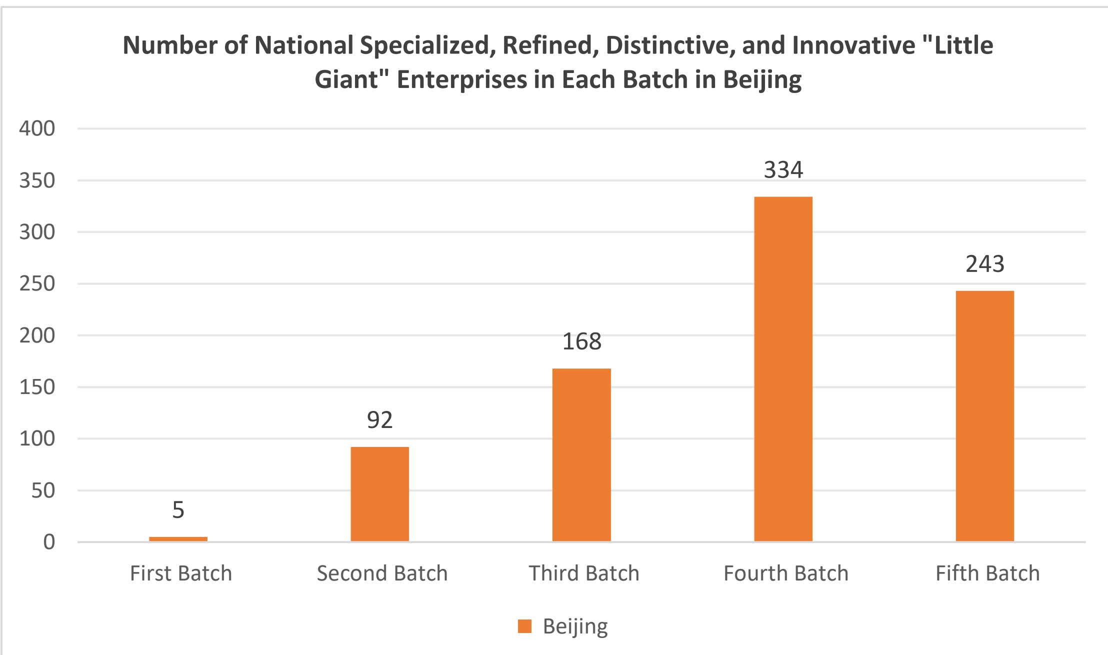


Figure 6: Number of National-Level Specialized, Refined, Distinctive, and Innovative "Little Giant" Enterprises in Beijing by Batch

These enterprises are concentrated in high-value-added manufacturing sectors. The top three industries by number of national-level "Little Giant" enterprises are: electronic equipment manufacturing (16 national-level enterprises), pharmaceutical manufacturing (8 national-level enterprises), and specialized equipment manufacturing (12 national-level enterprises) (Table 1). Municipal-level specialized, refined, distinctive, and innovative enterprises are similarly concentrated in these sectors (e.g., 63 in pharmaceutical manufacturing, 60 in electronic equipment manufacturing, and 52 in specialized equipment manufacturing), collectively forming the backbone supporting industrial chain modernization.

Table 1: Number of Top Ten Specialized, Refined, Distinctive, and Innovative "Little Giant" Enterprises in Beijing's Manufacturing Sector as of 2022

Industry	Number of National-Level Enterprises	Number of Municipal-Level Enterprises
Specialized Equipment Manufacturing	12	52
General equipment manufacturing	2	24
Computer, Communication, and Other Electronic Equipment Manufacturing	16	60
Electrical Machinery and Equipment Manufacturing	6	45
Metal Products Industry	3	17
Chemical Raw Materials and Chemical Products Manufacturing	6	18
Pharmaceutical Manufacturing	8	63
Non-metallic Mineral Products Manufacturing	2	22
Rubber and Plastic Products Industry	-	9
Automotive Manufacturing	1	5
Total	56	315

2.2 Current Status of Energy Consumption Structure and Utilization Efficiency

Beijing's energy consumption structure continues to optimize, with renewable energy sources such as solar and wind power steadily increasing their share. This has gradually reduced the manufacturing sector's dependence on traditional fossil fuels, effectively lowering carbon emissions. Additionally, coal consumption has significantly decreased, with modern manufacturing coal use dropping to near-zero levels by 2017. Urban heating and industrial processes have largely transitioned to clean energy alternatives. The power structure continues to improve, with increased external power transmission channels expanding transmission capacity to 34 million kilowatts. This has formed a "multi-directional, multi-source, diversified" power reception pattern and a grid structure characterized by "ring network support, multi-point injection, and local consumption."

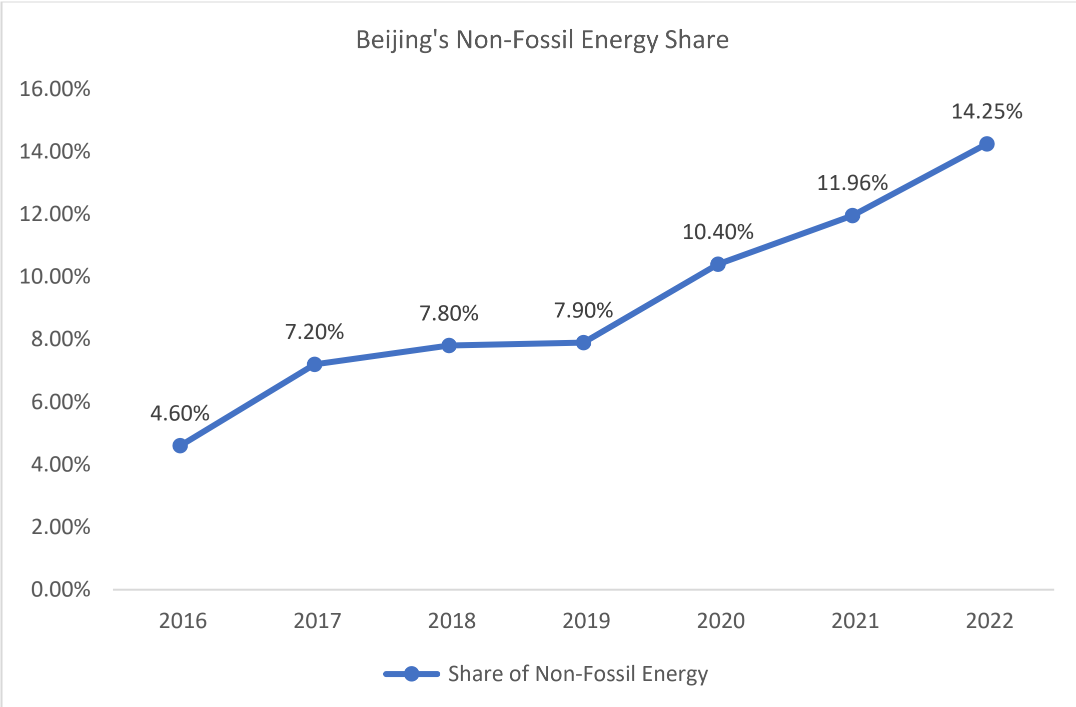


Figure 7: Non-Fossil Energy Share in Beijing

As shown in Figure 8, energy efficiency across modern manufacturing sectors in the capital has steadily improved. The electrical machinery and equipment manufacturing, instrument and meter manufacturing, specialized equipment manufacturing, and general equipment manufacturing sectors have demonstrated a steady upward trend, reaching 600,000-700,000 yuan/ton of standard coal equivalent in recent years. The automotive manufacturing sector has maintained energy efficiency at 350,000-450,000 yuan/ton of standard coal equivalent. The chemical raw materials and chemical products manufacturing sector exhibits the lowest energy efficiency, ranging from 20,000 to 50,000 yuan per ton of standard coal. The industries are ranked from highest to lowest energy efficiency as follows: electrical machinery and equipment manufacturing, instrument and meter manufacturing, specialized equipment manufacturing, automotive manufacturing, general equipment manufacturing, computer, communications, and other electronic equipment manufacturing, pharmaceutical manufacturing, railway, shipbuilding, aerospace, and other transportation equipment manufacturing, and chemical raw materials and chemical products manufacturing.

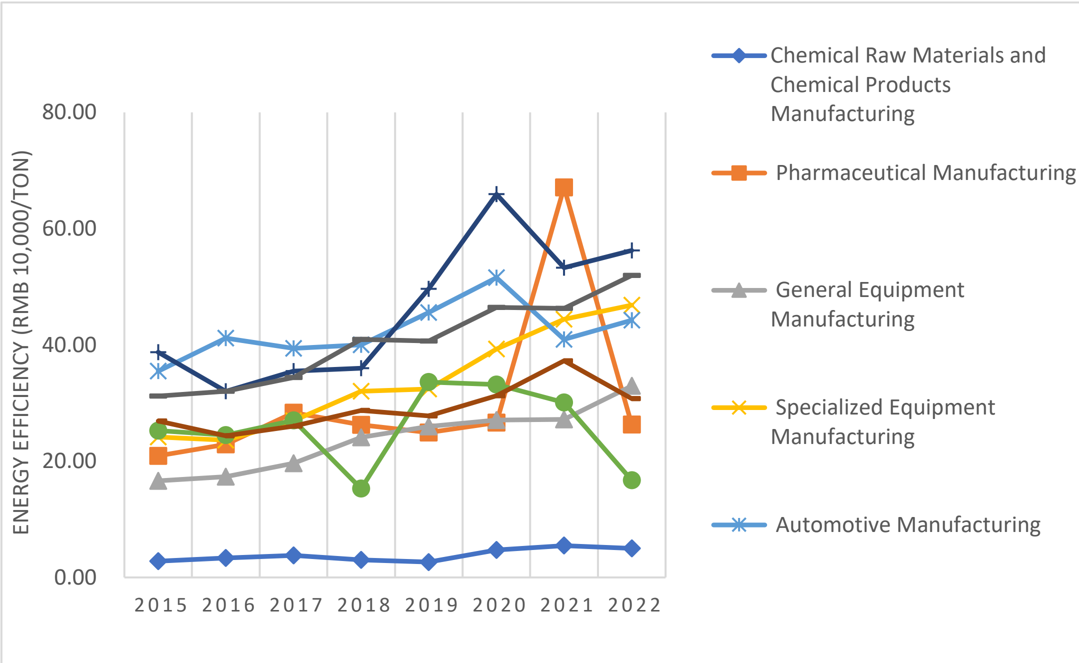


Figure 8: Energy Efficiency Across Industries

2.3 Current Status of Low-Carbon Technology and Process Application

Beijing has achieved remarkable results in establishing a green manufacturing system, which has become a key government initiative to promote low-carbon development in manufacturing. [11] By 2022, Beijing had certified a cumulative total of 116 green factories and 21 green supply chain management demonstration enterprises. Numerous companies actively participated in these initiatives, yielding positive outcomes in energy conservation, emission reduction, and resource utilization, as shown in Table 2.

Table 2: Batches of National-Level Green Factories, Green Industrial Parks, Green Design Products, by Batch

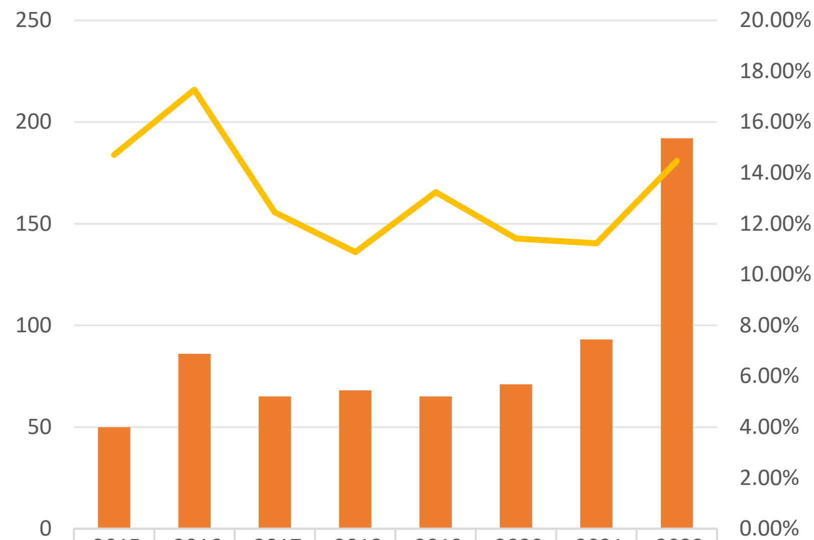
Batch	Green Factories	Green Industrial Parks	Green Design Products	Green Supply Chain Management Demonstration Enterprises
First Batch	8	0	0	0
Second Batch	4	0	0	0
Third batch	10	1	45	0
Fourth Batch	18	0	10	6
Fifth Batch	27	0	3	5
Sixth Batch	29	0	13	8
Seventh Batch	20	1	7	2
Total	116	2	78	21

Outstanding capacity for low-carbon transformation driven by technological innovation. Investment in scientific research and development has increased. As shown in Table 3, Beijing's R&D expenditure has grown year by year, while the number of R&D institutions has remained stable. Enterprise R&D activities are active, and the integration of innovation resources among universities, research institutions, and enterprises provides support for the R&D and application of low-carbon technologies, driving the low-carbon upgrading of industries. According to the report, Beijing ranks among the top global science and technology innovation clusters, and its intellectual property strength has ranked first in the country for ten consecutive years.

Table 3: Beijing's Internal R&D Expenditures and Number of R&D Institutions

Year	Total Internal R&D Expenditure in Manufacturing (RMB 10,000)	Total Internal R&D Expenditure (RMB 10,000)	Number of R&D Institutions (units)
2021	285,753.8	23,265,792.6	381.74
2020	2,758,939.15	22,335,870	382
2019	2,660,339.4	18,707,700.8	383
2018	2,613,921.6	15,796,512.3	382
2017	2,471,278.9	14,845,762.3	391
2016	23,650,340	13,840,231	396
2014	2035064	11850469	392

Low-carbon technology R&D has yielded substantial results. As of September 2024, Beijing held 1,135 valid low-carbon and emission-reduction technology patents, as shown in Figure 9. Significant breakthroughs have been achieved in fields such as new energy, providing technological support for the low-carbon transformation of manufacturing [12].



	2015	2016	2017	2018	2019	2020	2021	2022
Number of Patents in Beijing	50	86	65	68	65	71	93	192
Share of National Total	14.71%	17.27%	12.45%	10.88%	13.24%	11.41%	11.23%	14.47%

Figure 9: Number of Valid "Low-Carbon" and "Emission Reduction" Patents in Beijing and Their Share of the National Total

2.4 Current Status of Policy, Regulations, and Standards System

Guided by the Beijing Action Plan for Carbon Peaking and Carbon Neutrality [13], a "1+N" policy framework has been established (including the manufacturing sector-specific plan, the 14th Five-Year Plan for Green and Low-Carbon Development in Manufacturing [14]). This framework sets a binding target to reduce manufacturing carbon emissions intensity by 20% by 2025 compared to 2020 levels. Through a dual approach of "positive incentives + negative constraints," it promotes the transformation of modern manufacturing toward greener, circular, and low-carbon practices.

Beijing has established a multi-dimensional incentive mechanism. In financial support, the city implements offer a 30% interest subsidy at the 3-year LPR rate for national-level green factories [15]. It also issues to prioritize sectors like hydrogen energy and smart grids, with a 2023 issuance volume of 12 billion yuan on the Beijing Stock Exchange, featuring coupon rates 0.8-1.2 percentage points lower than conventional bonds. For technological breakthroughs, the city offered up to 80 million yuan in funding to teams advancing technologies like CCUS and solid waste utilization—such as supporting Shougang Group's CO_2 chemical production project. [16] Concurrently, the "Green Process Replacement Plan" provides 30% subsidies on equipment investments for enterprises replacing VOCs processes with eco-friendly alternatives. For market incentives, Beijing participates in the national carbon market expansion pilot, incorporating manufacturing enterprises with annual energy consumption exceeding 10,000 tons of standard coal into quota management while allowing 5% emissions to be offset with CCERs. A "Green Credit" system has been established, where enterprises earn credits through initiatives like installing rooftop solar panels and obtaining product carbon footprint certifications, granting them priority treatment in land use approvals and environmental impact assessments [17].

Beijing has established a green development institutional framework for manufacturing centered on carbon emission constraints, clean production standards, and energy structure transformation. For carbon emission control, the city implements manage annual carbon quotas for key industries like steel and petrochemicals, imposing a punitive carbon tax of 200 yuan per ton of CO_2 on excess emissions. It also required export-oriented products like automobiles and electronics to complete carbon labeling certification by 2025 [17]. For clean production oversight, it mandates triennial audits for enterprises with annual comprehensive energy consumption of 5,000 tons of standard coal or more. Non-compliant entities are placed on environmental credit blacklists. "Zero-waste industrial parks" standards are implemented in development zones, requiring over 90% utilization of industrial solid waste and 100% disposal of hazardous waste. [18] For energy consumption transformation, the province implements the nation's strictest mandating that enterprises above designated size use at least 25% renewable energy by 2025. Non-compliant enterprises lose eligibility to apply for high-end, precision, and cutting-edge projects. Simultaneously, new coal-fired boilers are prohibited, and existing coal-fired facilities must complete electrification or hydrogen-based replacement upgrades by 2025 [19].

3. Research Methods and Data

3.1 Data Sources

In its research report, the Beijing Municipal Bureau of Statistics defines modern manufacturing as an integrated industrial sector that processes agricultural products and other raw materials using advanced and practical technologies, and assembles various components. [20] Given the high-tech and high-value-added characteristics of modern manufacturing, combined with the structural features of Beijing's manufacturing sector, the Bureau categorizes modern manufacturing into five major types: electronics, electromechanical, transportation, pharmaceuticals, and others. This study employs the classification of Beijing's modern manufacturing sector outlined in the "Catalog and Structural Classification of Modern Manufacturing Industries", as detailed in Table 4.

Table 4: Classification of Modern Manufacturing Industries in the Capital

Type	Country Code for Economic Activities	Industry
Electronics	39	Computer, Communication, and Other Electronic Equipment Manufacturing
Electromechanical	34	General Equipment Manufacturing
	35	Special-purpose equipment manufacturing
	38	Electrical Machinery and Equipment Manufacturing
	40	Instrument and Meter Manufacturing
Transportation Equipment	36	Automotive Manufacturing
	37	Railway, Shipbuilding, Aerospace, and Other Transportation Equipment Manufacturing
Pharmaceuticals	27	Pharmaceutical Manufacturing
	35	Specialized Equipment Manufacturing
Other	26	Chemical Raw Materials and Chemical Products Manufacturing

Note: Industries with relatively small quantities as listed in the "Catalog and Structural Classification of Modern Manufacturing Industries" (Beijing Statistics Bureau Document [2012] No. 43) are not analyzed in detail.

To better align with Beijing's strategic requirements for low-carbon development in modern manufacturing, the sample data covers the period from 2015 to 2022. Data used in this report, except for carbon dioxide emissions from modern manufacturing, are sourced from the Beijing Statistical Yearbook (2015-2022) and the China Industrial Statistical Yearbook. Carbon dioxide emissions from modern manufacturing are calculated within this report. Missing data for specific years are supplemented using linear interpolation.

3.2 Carbon Emissions Measurement Methodology

This report primarily references Feng Xiaojing's methodology [21] for calculating manufacturing carbon emissions, employing the standard coal method proposed by the IPCC in 2006 to estimate CO_2 emissions. Following the classification standards of the China Energy Statistical Yearbook, final energy consumption is subdivided into seven categories: coal, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas (LPG), and natural gas. Estimates are calculated accordingly using the following formula:

$$C=\sum_{i=1}^{7} A_i B_i \quad (1)$$

In Equation 1, C represents carbon emissions, A_i denotes the consumption of energy source i (in tons of standard coal), Bi is the carbon emission factor for energy source i, and i indicates the type of energy source. The specific values for each relevant coefficient are shown in Table 5.

Table 5: Relevant Coefficients for Various Energy Sources

Energy Type	Average Lower Heating Value	Conversion Factor to Standard Coal	Carbon Content per Unit Heat Value	Carbon Oxidation Rate	Carbon Dioxide Emission Factor
Coal	20934 kJ/kg	0.7143 kgce/kg	26.37 TC/TJ	0.94	1.9027kg CO_2/k
Gasoline	43124 kJ/kg	1.4714 kgce/kg	18.9 TC/TJ	0.98	2.9287kg CO_2/k
Kerosene	43124 kJ/kg	1.4714 kgce/kg	19.6 TC/TJ	0.98	3.037 kg CO_2/k
Diesel	42705 kJ/kg	1.4571 kgce/kg	20.2 TC/TJ	0.98	3.0998kg CO_2/k
Fuel Oil	41816 kJ/kg	1.4286 kgce/kg	21.1 TC/TJ	0.98	3.170 kg CO_2/k
Liquefied Petroleum Gas	50242 kJ/kg	1.7143 kgce/kg	17.2 TC/TJ	0.98	3.105 kg CO_2/k
Natural gas	38,979 kJ/m^3	1.33 kgce/m^3	15.3 TC/TJ	0.99	2.1649kg CO2/m^3

Note: Standard coal conversion factor data sourced from the 2021 China Energy Statistical Yearbook; Carbon dioxide emission factor = Average lower heating value × Carbon content per unit heat value × Carbonization rate × (44/12); Carbon content per unit heat value and carbonization rate data sourced from the Provincial Greenhouse Gas Inventory Compilation Guidelines (Development and Reform Commission Office Circular [2011] No. 1041); Average lower heating value and carbon content per unit heat value data sourced from General Rules for Comprehensive Energy Consumption Calculation (GB/T 2589-2020).

3.3 Low-Carbon Development Level Evaluation System

3.3.1 Indicator Selection and Construction Methodology

This study constructs an evaluation indicator system to determine the importance of each indicator in influencing the low-carbon development of Beijing's modern manufacturing sector, analyzing its low-carbon development level from 2015 to 2022. Following principles of scientific rigor, comprehensiveness, and operational feasibility, nine secondary indicators across two levels were selected to comprehensively evaluate the low-carbon development level of Beijing's modern manufacturing sector.

Table 6: Comprehensive Evaluation Indicator System for Low-Carbon Development in Beijing's Modern Manufacturing Sector

Primary Indicators	Secondary Indicators	Indicator Measurement	Attribute
Manufacturing Modernization	Share of Modern Manufacturing	Output Value of Modern Manufacturing / Total Manufacturing Output Value	Positive
	Share of modern manufacturing revenue	Modern manufacturing operating revenue / Manufacturing operating revenue	Positive
	Growth rate of modern manufacturing output value	Growth rate of output value in modern manufacturing	Positive
	Labor Productivity in Modern Manufacturing	Modern Manufacturing Output Value / Modern Manufacturing Workforce	Positive
	Manufacturing Employment Structure	Modern Manufacturing Employment / Manufacturing Employment	Positive
Modern Manufacturing Low-carbon	Electricity Consumption per Unit of Output in Modern Manufacturing	Electricity Consumption in Modern Manufacturing / Output Value of Modern Manufacturing	Negative
	Energy Consumption per Unit of Output in Modern Manufacturing	Output value of modern manufacturing / Energy consumption	Positive
	Per capita CO2 emissions in modern manufacturing	CO2 emissions from modern manufacturing / Number of people employed in modern manufacturing	Negative
	CO2 Emission Intensity of Modern Manufacturing	CO_2 emissions from modern manufacturing / Output value of modern manufacturing	Negative

3.3.2 Development Level Assessment

To ensure scientific rigor and precision in the assessment, this report employs the entropy method to assign weights to the comprehensive evaluation indicators for the low-carbon development level of Beijing's modern manufacturing sector.

1) Data Preprocessing

The range method was applied to standardize the indicator values (x_{ij}) within the evaluation framework, using the following formula:

Positive indicators: $X_{ij}=\frac{x_{ij}-x_{min}}{x_{max}-x_{min}}$

Reverse indicators: $X_{ij}=\frac{x_{max}-x_{ij}}{x_{max}-x_{min}}$

2) Calculate indicator information entropy E_j

$$P_{ij}=\frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \tag{2}$$

$$E_j=\frac{-1}{Ln(n)}\sum_{i=1}^{n} P_{ij}\times Ln(P_{ij}) \tag{3}$$

3) Calculate indicator weights ω_j

$$\omega_j=\frac{D_j}{\sum_{j=1}^{n} D_j} \tag{4}$$

$$D_j=1-E_j \tag{5}$$

The linear weighting method yields the low-carbon development level index for Beijing's modern manufacturing sector Y_i

$$Y_i=\sum_{j=1}^{\mathrm{k}} \omega_j \times X_{ij} \tag{6}$$

3.4 STIRPAT Model

3.4.1 Model Construction

This study adopts the fundamental theoretical framework of the STIRPAT model [22], expressed as:

$$I_i = \alpha_i * P_i^b * A_i^c * T_i^d \quad (7)$$

where I, P, A, and T represent environmental level, population factor, wealth level, and technological level, respectively; b, c, and d denote the corresponding elasticity coefficients; andα_i denote the random disturbance term.

To eliminate potential heteroscedasticity inherent in the model, logarithmic transformation is typically applied, yielding the following expression:

$$\ln I_i = \ln \alpha_i + b + \ln P_i + c + \ln A_i + d + \ln T_i \quad (8)$$

This study employs four control variables to construct the following model: the ratio of annual output value to primary energy consumption in modern manufacturing, representing energy efficiency (T); technological investment in modern manufacturing, representing economic level (RE); the number of employees in modern manufacturing (P); and the annual output value of modern manufacturing (A).

$$\ln C = \beta_1 \ln P + \beta_2 \ln A_i + \beta_3 \ln T + \beta_4 \ln RE \quad (9)$$

where β denotes the elasticity coefficient of the corresponding indicator.

3.4.2 Variable Descriptions

This study selects Beijing's total carbon emissions from 2015 to 2022 as the dependent variable. The total emissions are calculated using the IPCC carbon factor verification method, incorporating seven energy sources including gasoline, diesel, and natural gas. The calculation formula is as follows:

$$CO_2 = \sum_{i=1}^{7} E_i * NCV_I * CEF_I \quad (10)$$

In the equation 10, CO_2 represents the total carbon dioxide emissions in Beijing from 2015 to 2022; i denotes the energy type; Ei, NCVi, and CEFi represent fuel consumption, average lower heating value, and carbon emission factor, respectively.

4. Results and Discussion

4.1 Carbon Emissions from Beijing's Modern Manufacturing Sector

4.1.1 Analysis of Overall Carbon Emissions from Beijing's Modern Manufacturing Sector

Using data from 2015 to 2022, the total carbon emissions from Beijing's modern manufacturing sector and its proportion of total manufacturing emissions were calculated. As shown in Figure 10, both the carbon emissions from modern manufacturing and their share of total manufacturing emissions exhibited an overall downward trend, decreasing from 995,300 tons in 2015 to 299,100 tons in 2020, with a fluctuating increase observed in 2019. Starting from 2020, carbon emissions showed a slight increase but remained largely stable, accounting for approximately 6.6% of total emissions by 2022.

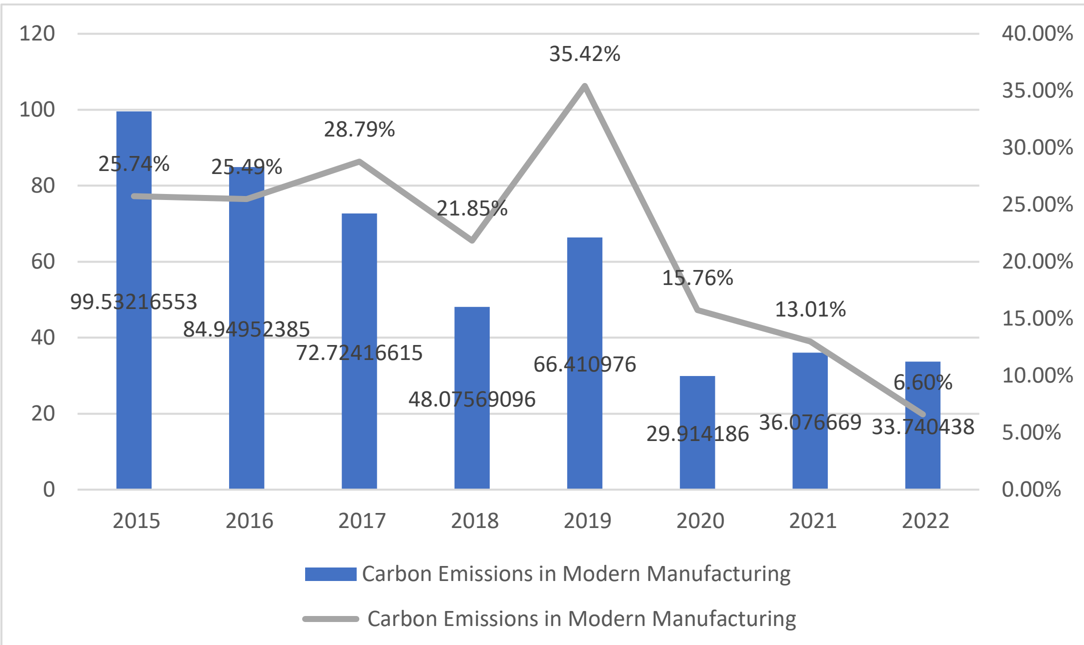


Figure 10: Carbon Emissions from Modern Manufacturing in Beijing and Their Proportion, 2015–2022

4.1.2 Analysis of Carbon Emissions by Sub-sector in Beijing's Modern Manufacturing Industry

Within the electronics sector, typified by the computer, communications, and other electronic equipment manufacturing industry, both carbon emissions and carbon emission intensity showed a consistent annual decline from 2015 to 2020. A particularly sharp decrease in carbon emission intensity occurred in 2018. The electromechanical sector primarily encompasses general equipment manufacturing, specialized equipment manufacturing, electrical machinery and equipment manufacturing, and instrument manufacturing. Overall, carbon emissions across these sectors showed a downward trend. The general machinery manufacturing sector achieved particularly notable reductions, with emissions plummeting from 124,000 tons in 2015 to 28,000 tons in 2022. Current carbon emission intensity for this sector ranges between 30 and 40 tons per 100 million yuan of output value.

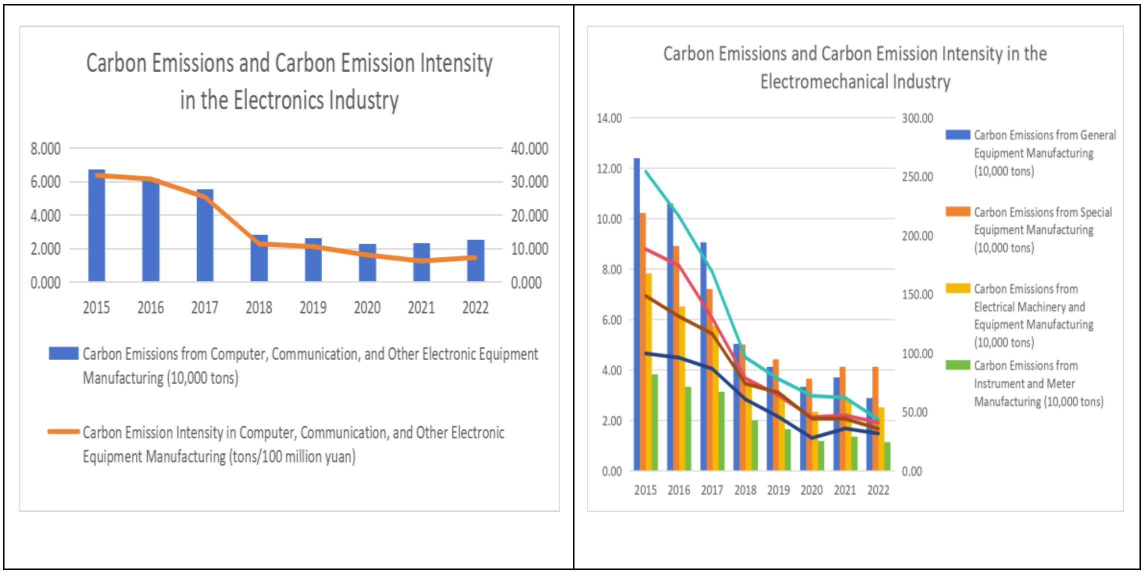


Figure 11: Carbon Emissions and Carbon Emission Intensity in the Electronics and Electromechanical Industries

The transportation sector encompasses the automotive manufacturing industry and the rail, shipbuilding, aerospace, and other transportation equipment manufacturing industries. Although there is a significant gap in carbon emissions between these two industries, both show an overall downward trend. Carbon emissions in the automotive manufacturing sector fell steadily from 350,300 tons to 95,200 tons. Carbon emission intensity decreased continuously between 2015 and 2020, though it saw a slight rebound in the subsequent two years, stabilizing around 30 tons per 100 million yuan. Carbon emissions in the railway, shipbuilding, aerospace, and other transportation equipment manufacturing sector decreased from 84,900 tons to 15,600 tons, remaining significantly lower than the automotive sector. Its carbon emission intensity was substantially higher than the automotive sector from 2015 to 2018 but gradually declined to comparable levels thereafter. The pharmaceutical sector primarily refers to pharmaceutical manufacturing. Its carbon emissions and carbon emission intensity declined significantly between 2015 and 2017, remaining relatively stable from 2018 to 2022. Carbon emission intensity reached a low point of 13.28 tons per 100 million yuan in 2021, primarily attributable to the impact of the pandemic.

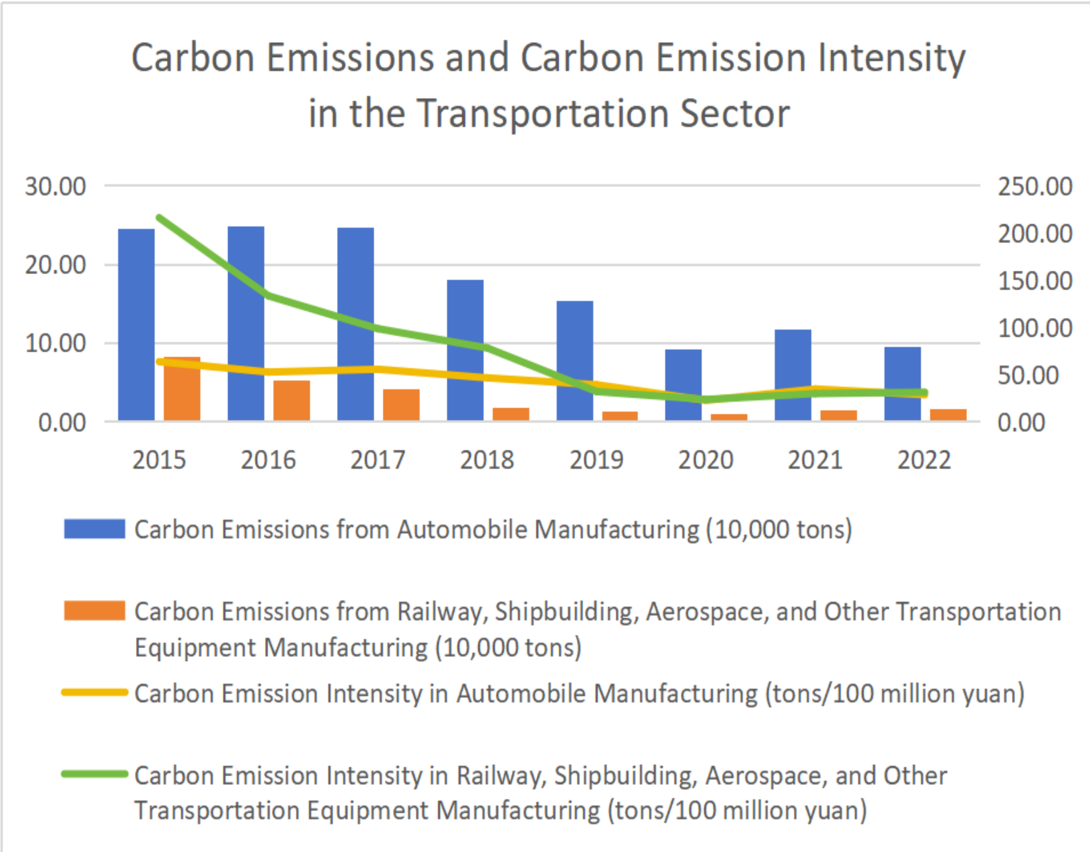


Figure 12: Carbon Emissions and Carbon Emission Intensity in Transportation

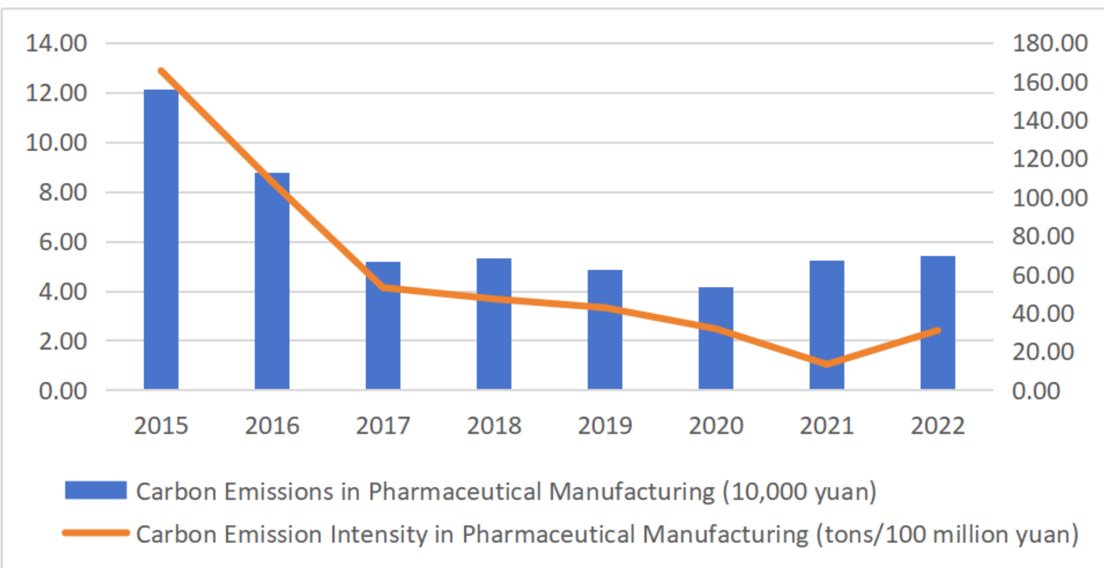


Figure 13:Carbon Emissions and Carbon Emission Intensity in Pharmaceutical Industries

Other sectors primarily encompass the chemical raw materials and chemical products manufacturing industry. This sector experienced a substantial increase in both carbon emissions and carbon emission intensity in 2019, reaching 268,900 tons and 995.69 tons per 100 million yuan, respectively. This surge was primarily driven by fuel oil consumption. Excluding 2019, carbon emissions in other years showed a steady downward trend. However, its carbon emission intensity reached 139.43 tons per 100 million yuan, far exceeding that of other industries.

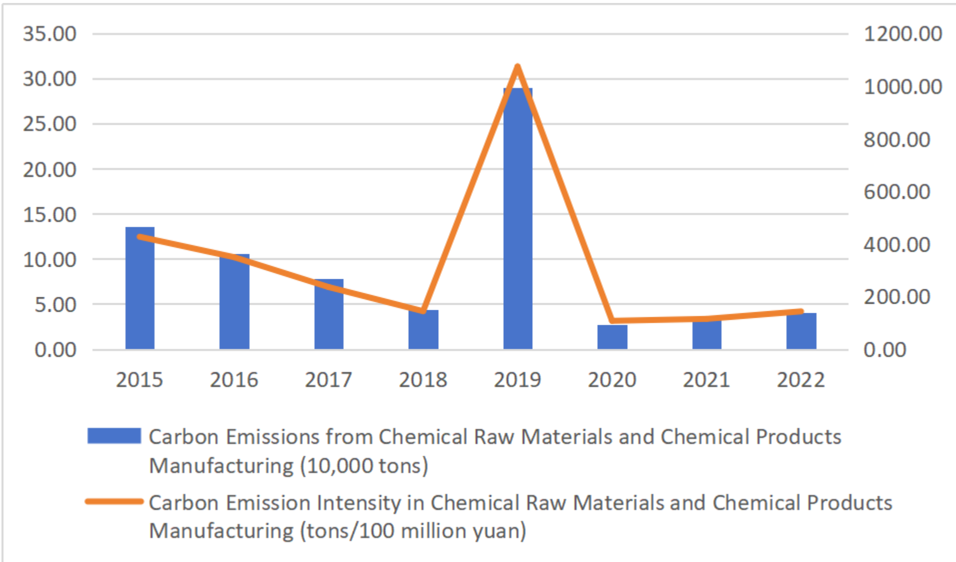


Figure 14: Carbon Emissions and Carbon Emission Intensity of Other Industries

As shown in Figure 15, the ranking of carbon emission intensity across industries from 2015 to 2022 indicates that the chemical raw materials and chemical products manufacturing sector consistently ranked highest, while the computer, electronic, and communication equipment manufacturing sector consistently ranked lowest. The rankings for the machinery and electrical equipment, transportation equipment, and pharmaceutical sectors fluctuated somewhat, but their carbon emission intensities in 2022 all fell within the range of 30-40 tons per 100 million yuan. Compared to the output value of large-scale enterprises in Beijing's modern manufacturing sectors, the output value of the computer, electronic, and communication equipment manufacturing industry has increased annually. In 2021, it surpassed the automotive manufacturing industry to become the largest modern manufacturing sector. In recent years, its carbon intensity has also continuously decreased to below 10 tons per 100 million yuan, indicating strong low-carbon performance. The chemical raw materials and chemical products manufacturing industry has the lowest output value and the highest carbon intensity, reflecting relatively poor low-carbon performance.

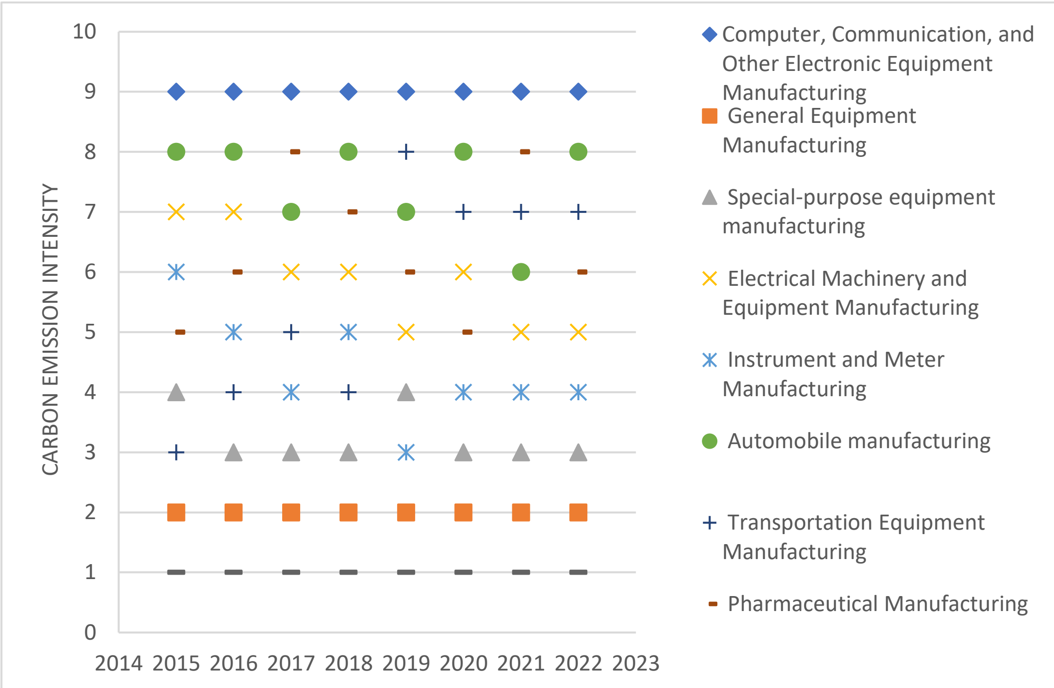


Figure 15: Ranking of Carbon Emission Intensity Across Modern Manufacturing Sectors, 2015-2022

4.2 Dynamic Changes in Low-Carbon Development Levels of Beijing's Modern Manufacturing Industries

Calculations yielded the weight of each secondary indicator within the system and its weight ranking, as shown in Table 7.

Table 7:Weighting of Low-Carbon Development Indicators for Modern Manufacturing

Secondary Indicator	Weight	Rank
Share of Modern Manufacturing	0.0836	8
Share of modern manufacturing revenue	0.0840	7
Growth rate of modern manufacturing output	0.0844	6
Labor productivity in modern manufacturing	0.1430	2
Employment Structure	0.1837	1
Electricity Consumption per Unit of Output in Modern Manufacturing	0.0934	5
Output value of modern manufacturing per unit of energy consumption	0.1404	3
Per capita CO2 emissions in modern manufacturing	0.0657	9
CO2 emission intensity of modern manufacturing	0.1219	4

By calculating the Low-Carbon Development Index for Beijing's Modern Manufacturing Sector (Figure 16), the overall low-carbon development level of Beijing's modern manufacturing industry showed a positive trend during the 2012–2022 period. Specifically, the index rose steadily from 0.2757 in 2015 to 0.8356 in 2021, representing a growth rate of 203.8%. This significant improvement demonstrates substantial progress in Beijing's efforts to advance low-carbon development within its modern manufacturing sector.

This growth trend can be attributed to the combined effects of multiple factors. On one hand, Beijing has implemented proactive and effective measures in technological innovation, industrial upgrading, and policy guidance, driving modern manufacturing toward low-carbon, intelligent, and high-end development. For instance, increased investment in R&D for energy-saving and environmental protection technologies has encouraged enterprises to adopt advanced production processes and equipment, thereby reducing energy consumption and carbon emissions. On the other hand, efforts to adjust and optimize the industrial structure may have intensified, gradually phasing out outdated production capacity and increasing the proportion of modern manufacturing within the overall industrial system, which in turn elevated the overall level of low-carbon development.

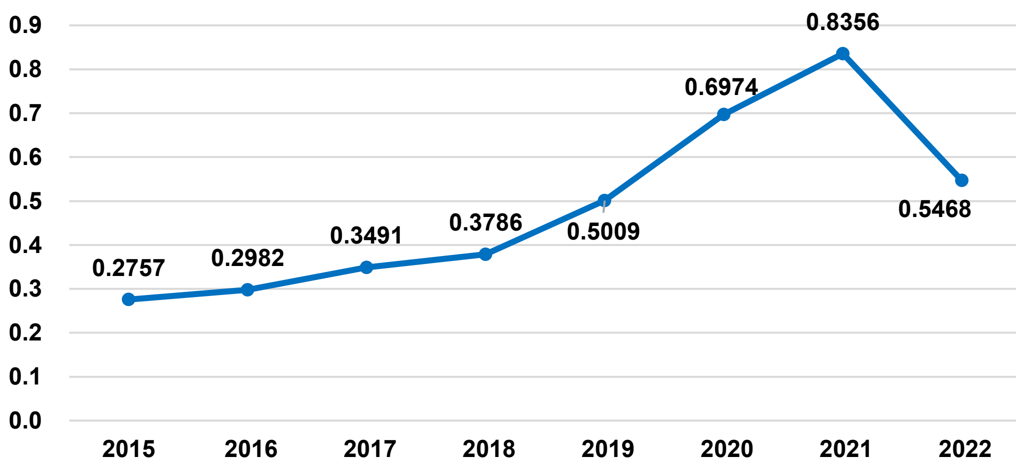


Figure 16: Beijing Modern Manufacturing Low-Carbon Development Level Index, 2015-2022

In 2022, this index experienced a certain degree of decline. Following the end of the pandemic, the scale of the pharmaceutical manufacturing industry significantly contracted, while other sectors had not fully resumed production. Market demand fluctuated, and industrial restructuring occurred. From the overall trend between 2015 and 2022, Beijing's modern manufacturing industry achieved a notable improvement in its low-carbon development level, yielding positive results.

4.3 Analysis of Carbon Emission Influencing Factors

4.3.1 Stability Test

This report employed SPSS software to conduct stability analysis on Beijing's time-series data from 2015 to 2022. As shown in Table 8, the unit root test results for the time-series data were highly significant, indicating that the original data were non-stationary. After applying second-order differencing, all datasets successfully passed the stationarity test.

Table 8: Unit Root Test Results

Variable	ADF Statistic	P	Test Result
lnP	-3.478	0.013	Stationary
lnA	-3.646	0.981	Stationary
lnT	-3.478	0.154	Stationary
lnRE	-3.478	0.939	Stationary

As shown in Table 9, the residuals of all variables passed the unit root test at the 5% level, indicating a long-term stable equilibrium relationship between the independent and dependent variables.

Table 9: Cointegration Test Results

Variable	ADF Statistic	P	Test Result
lnC	-6.678	0.002	Stationary
lnP	-6.678	0.0002	Stationary
lnA	-6.678	0.0002	Steady
lnT	-6.678	0.0001	Steady
lnRE	-6.678	0.0001	Stationary

4.3.2 Ridge Regression Analysis

OLS regression revealed a regression relationship among the variables, but the VIF value was 55.849, indicating severe multicollinearity among the variables.

Table 10: OLS Regression Results

<table>
<tr><th colspan="3">Unstandardized Coefficients</th><th>Standardized Coefficients</th><th>t</th><th>P</th><th>VIF</th><th>R^2</th><th>Adjusted R^2</th><th>F</th></tr>
<tr><td></td><td>β</td><td>Standard Error</td><td>Beta</td><td>0</td><td>0</td><td>0</td><td rowspan="6">0.929</td><td rowspan="6">0.876</td><td rowspan="6">17.502 (P=0.009)</td></tr>
<tr><td>Constant</td><td>516.15</td><td>256.641</td><td>0</td><td>2.011</td><td>0.115</td><td>0</td></tr>
<tr><td>lnP</td><td>-64.135</td><td>32.971</td><td>-0.479</td><td>-1.945</td><td>0.124</td><td>3.423</td></tr>
<tr><td>lnA</td><td>1.153</td><td>1.161</td><td>0.988</td><td>0.994</td><td>0.377</td><td>55.849</td></tr>
<tr><td>lnT</td><td>-0.894</td><td>0.445</td><td>-1.113</td><td>-2.012</td><td>0.115</td><td>0</td></tr>
<tr><td>lnRE</td><td>-0.894</td><td>0.445</td><td>-1.113</td><td>-2.012</td><td>0.115</td><td>0</td></tr>
</table>

To address the challenge of multicollinearity, this study employed ridge regression estimation in SPSS 27.0 for in-depth analysis. The resulting ridge plots are shown below.

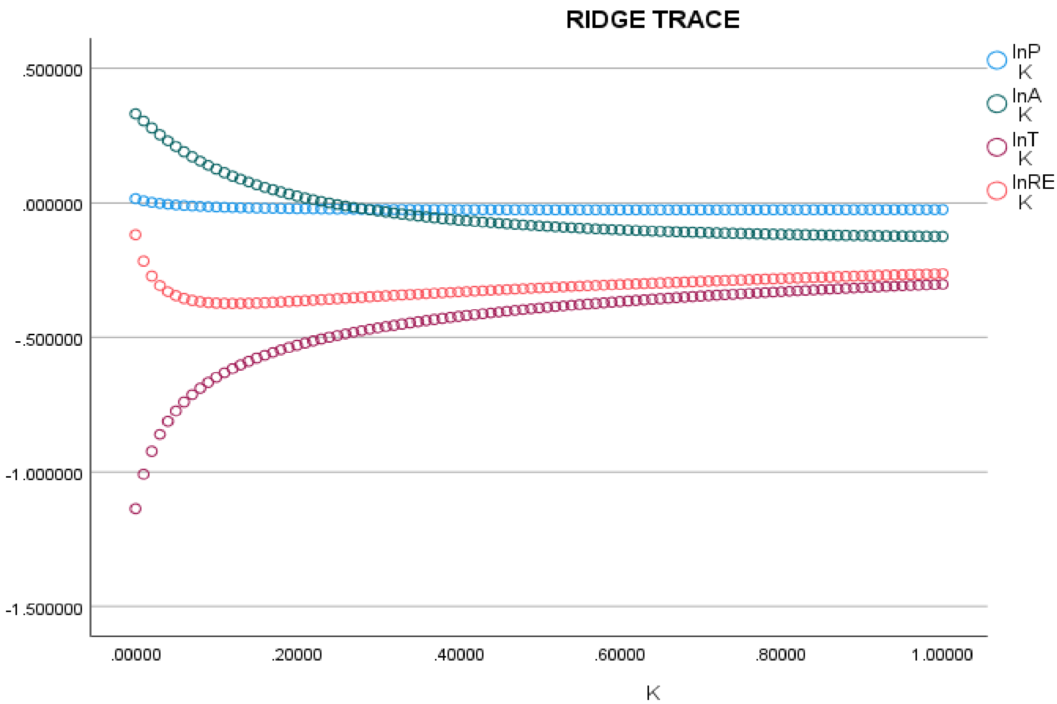


Figure 17: Ridge Trace Plot

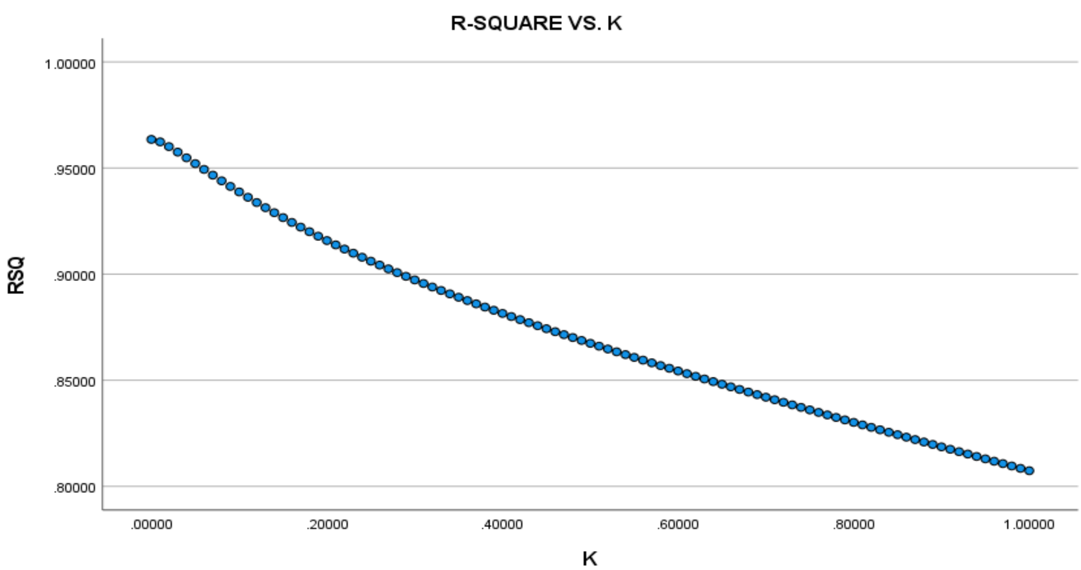


Figure 18: Variation Curve of Ridge Parameter k and R2

Based on the ridge trace plot, the ridge trace stabilizes when the ridge parameter k approaches 0.1. Therefore, we selected k=0.1 for analysis, with results presented in Table 11 below.

Table 11: Ridge Regression Results

K=0.1	**Non-standardized Coefficient**		**Standardized Coefficient**	**t**	**P**	**R^2**	**Adjusted R^2**	**F**
	B	Standard Error	Bata					
Constant	9.471	2.85	0	3.323	0.045	0.939	0.857	11.499
lnP	-0.012	0.103	-0.015	-0.117	0.914			
lnA	0.197	0.291	0.125	0.677	0.547			
lnT	-0.203	0.053	-0.648	-3.797	0.032			
lnRE	-0.299	0.136	-0.372	-2.206	0.115			

The ridge regression equation derived from Table 11 is:

$$\ln C = -0.015\ln P + 0.125\ln A - 0.648\ln T - 0.372\ln RE \tag{11}$$

A goodness-of-fit test on the prediction results yields: The P-value in the test result is 0.36, which is significantly greater than 0.05. This indicates no significant difference between the two sets of data, meaning the predicted values and actual values exhibit a good fit.

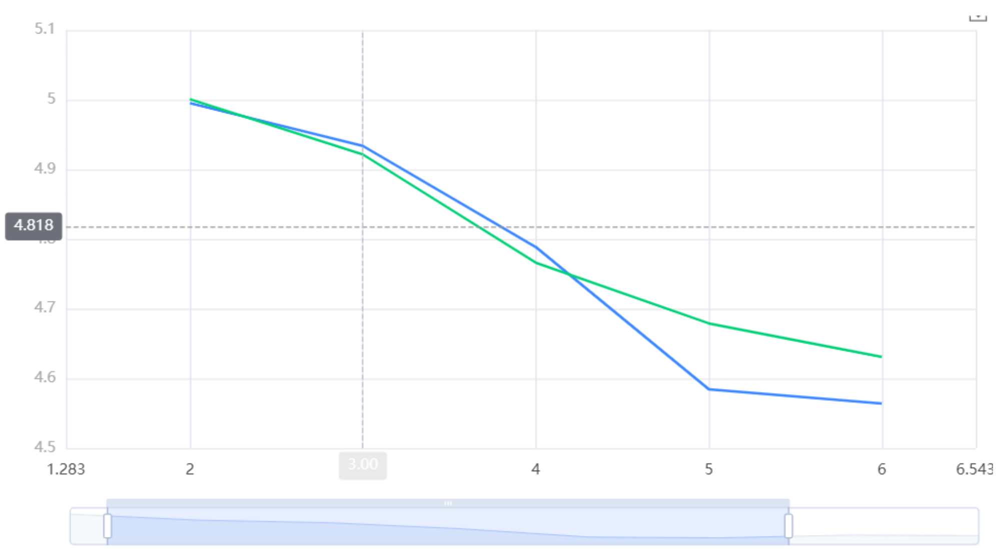


Figure 19: Comparison of Predicted and Actual Values

Through the above analysis and calculations, it is clearly established that the ridge regression equation exhibits a relatively good fitting effect, effectively reflecting the intrinsic relationship between carbon emissions in modern manufacturing and various control variables. The results reveal that the number of employees, energy efficiency, and technological investment are negatively correlated with carbon emissions, while industrial output value is positively correlated with carbon emissions.

Among these variables: ① Energy efficiency exerts the most significant impact on carbon emissions in modern manufacturing. A 1% increase in energy efficiency reduces carbon emissions by 0.648%. ② The elasticity coefficient for technological investment is 0.372%, indicating that a 1% increase in technological investment reduces carbon emissions by 0.372%. Technological investment substantially influences carbon emissions in modern manufacturing. With continuous technological advancement, the application of new technologies and processes enhances production efficiency, reduces energy consumption, and propels modern manufacturing toward low-carbon and clean development. For instance, smart manufacturing technologies enable intelligent control of production processes, optimize workflows, and minimize energy waste and carbon emissions [23]. The research, development, and application of new energy technologies provide modern manufacturing with cleaner, more efficient energy sources, reducing reliance on traditional fossil fuels and thereby lowering carbon emissions [24]. ③ The elasticity coefficient for the number of employees is -0.015, indicating a relatively minor impact on carbon emissions in modern manufacturing that can be largely disregarded. Although changes in the workforce have a limited direct effect on carbon emissions.

In summary, to achieve low-carbon development in modern manufacturing, emphasis should be placed on enhancing energy efficiency and increasing technological investment. Concurrently, industrial scale should be appropriately controlled, human resource allocation optimized, and modern manufacturing propelled toward a greener, more sustainable trajectory.

4.4 Challenges Facing Low-Carbon Development in Beijing's Modern Manufacturing Sector

4.4.1 Industrial Structure Challenges in Modern Manufacturing

Currently, China is in the late stages of industrialization, and Beijing's modern manufacturing sector is undergoing a transformation toward a "low-emission, high-growth" model, facing dual pressures of output growth and carbon sequestration/reduction. Optimizing and upgrading the industrial structure of modern manufacturing is crucial for low-carbon transformation. Analysis of Beijing's modern manufacturing output structure and carbon emissions across sectors reveals significant issues in the chemical raw materials and chemical products manufacturing sector. This sector exhibits low output value but high carbon emissions, indicating its relative inefficiency within the modern manufacturing industry composition. This negatively impacts the overall low-carbon transformation of the industry, necessitating industrial restructuring and upgrading.

Additionally, the computer, communications, and electronic equipment manufacturing sector and the automotive manufacturing sector exhibit opposing development trends. The electronics manufacturing sector has surpassed the automotive sector to become the largest in terms of output value. While this shift reflects dynamic adjustments in the industrial structure, it may also give rise to new challenges. For instance, the automotive manufacturing sector, as a traditional strength of Beijing, is actively pursuing integrated development with the new energy vehicle industry. It faces technical and market challenges, but a successful transition would yield significant environmental benefits. Simultaneously, the rapid growth in output value of the electronics manufacturing sector may introduce new pressures on energy consumption and carbon emissions. With the development of digitalization, artificial intelligence, and large-scale models, the number and scale of data centers continue to expand, consuming enormous amounts of electricity. A single large data center may consume tens of millions or even hundreds of millions of kilowatt-hours annually.

From the perspective of Beijing's overall modern manufacturing structure, there is a lack of effective coordination mechanisms among industries for low-carbon transformation. The pace of low-carbon transition varies across sectors, failing to form an integrated structure that mutually reinforces and supports each other. For instance, the high carbon emissions in the chemical raw materials and chemical products manufacturing sector have not received effective support from other industries in terms of technology, energy, or resource sharing. This creates significant challenges for the overall industrial structure in transitioning toward a "low-emission, high-growth" model.

4.4.2 Energy Efficiency Challenges in Modern Manufacturing

While the overall carbon intensity of modern manufacturing has decreased, individual sectors exhibit distinct characteristics. Beijing's share of non-fossil energy continues to rise, reaching 14.25% in 2022. Further increasing the application proportion of non-fossil energy remains necessary to meet low-carbon transition requirements. Due to differing energy consumption characteristics across sectors, some high-carbon industries—such as chemical raw materials and chemical products manufacturing—may still rely heavily on fossil fuels, potentially limiting the overall pace of manufacturing sector carbon emission reductions.

Second, significant disparities exist in energy efficiency across industries, with some sectors urgently needing improvement. Industries like electrical machinery and equipment manufacturing, instrument and meter manufacturing, and specialized equipment manufacturing have demonstrated steady energy efficiency gains. Leading in technology-enabled, green, and low-carbon development, these sectors should be prioritized for empowerment and development during Beijing's construction of a science and technology innovation center. Conversely, manufacturing sectors closer to traditional heavy and chemical industries require accelerated transformation and upgrading. Sectors like chemical raw materials and chemical products manufacturing, as well as railway, shipbuilding, aerospace, and other transportation equipment manufacturing, exhibit relatively low energy efficiency levels. Their production technologies and equipment require breakthroughs in energy utilization, necessitating greater efforts to enhance industry-wide energy efficiency. During the low-carbon transition, continuous technological innovation is needed to accelerate energy efficiency improvements, enabling these sectors to better fulfill their role in energy conservation and emissions reduction while keeping pace with the broader industry's low-carbon transformation.

4.4.3 Technological Challenges in Modern Manufacturing

A major weakness in China's manufacturing sector is its high dependence on foreign high-tech imports. Similarly, the low-carbon development of Beijing's modern manufacturing industry places higher demands on technological innovation. From the perspective of Beijing's specialized, refined, distinctive, and innovative enterprises and strategic emerging industries, core technologies in modern manufacturing are unevenly distributed. While specialized, refined, distinctive, and innovative SMEs have core technology products filling gaps in key areas, their distribution across industries is concentrated in five sectors: general equipment manufacturing, specialized equipment manufacturing, computer, communications, and other electronic equipment manufacturing, electrical machinery and equipment manufacturing, and pharmaceutical manufacturing. Other sectors may be relatively weak in core technologies, potentially hindering the comprehensive development of modern manufacturing as a whole.

Simultaneously, technological innovation collaboration requires enhancement. Coordination among specialized, refined, distinctive, and innovative SMEs and across different industries may be insufficient. While strategic emerging industries provide modern manufacturing with new technologies, equipment, and solutions, leveraging the advantages of collaborative technological innovation remains essential for mutual advancement within the industrial chain.

Finally, the efficiency of converting technological innovation achievements remains low. For instance, while the new energy and energy-saving environmental protection industries provide clean energy and technologies, their practical application in modern manufacturing may face challenges such as high costs and low corporate acceptance. This results in inefficient conversion of technological achievements, preventing them from fully promoting the low-carbon and intelligent development of modern manufacturing.

5. Conclusions and Recommendations

5.1 Conclusions

Based on the current status of low-carbon development in Beijing's modern manufacturing sector, this study conducted carbon emission measurements for the sector, assessed its current level of low-carbon development, analyzed the factors influencing CO_2 emissions using the STRIPAT model, and further identified existing challenges in achieving low-carbon development. The study yields the following conclusions: ① Using the IPCC carbon emission factor method, we calculated the overall and sector-specific carbon emissions of Beijing's modern manufacturing industry. Results show that from 2015 to 2022, overall carbon emissions exhibited a downward trend with a rebound in 2019. Among all sectors, the chemical raw materials and chemical products manufacturing industry consistently had the highest carbon emission intensity, indicating significant sectoral divergence that requires targeted policy measures. ② An evaluation index system for modernization and low-carbon development in Beijing's modern manufacturing sector was established. Using the entropy method to calculate indicator weights, employment structure was identified as the most influential factor affecting low-carbon development. Significant progress in low-carbon transformation was achieved between 2012 and 2022. ③ Subsequently, the STRIPAT model was applied to analyze CO_2 emission drivers in modern manufacturing. Findings indicate that enhancing energy efficiency and technological innovation are the primary factors reducing CO_2 emissions in this sector.

5.2 Policy Recommendations

5.2.1 Improve Top-Level Design and Strengthen Policy Implementation

1) Develop a targeted action plan for low-carbon development in modern manufacturing

Based on an in-depth analysis of the low-carbon development status across various sectors of Beijing's modern manufacturing industry, formulate an action plan for low-carbon development in modern manufacturing. Focus on proposing specific technical measures and pathways for the transformation and upgrading needs of sectors such as chemical raw materials and chemical products manufacturing, railway, shipbuilding, aerospace, and other transportation equipment manufacturing, and automotive manufacturing. Additionally, conduct preliminary assessments of the potential significant increases in energy consumption and carbon emissions that may arise during the digitalization and artificial intelligence-enabled development processes in sectors like electrical machinery and equipment manufacturing, instrumentation manufacturing, and specialized equipment manufacturing. Proactively strengthen planning management to prepare for potential challenges.

Optimize and rationally arrange the collaboration between specialized, refined, distinctive, and innovative enterprises and various sectors of modern manufacturing in core technologies. Formulate policies, clarify objectives and tasks, guide the diffusion of high-tech innovations to support balanced industry development, and further enhance the synergistic innovation and integrated development between strategic emerging industries and modern manufacturing.

2) Refine enterprise classification support policies

Further refine support policies for enterprises of different scales. Encourage large enterprises to collaborate with specialized, refined, distinctive, and innovative SMEs, leveraging the core technological strengths of these SMEs to provide support in areas such as technology sharing and resource integration, thereby achieving industrial upgrading and jointly promoting low-carbon transformation of industrial chains. For SMEs, establish dedicated support mechanisms to organize technical exchange activities within industries, facilitating experience sharing and collaboration among SMEs to better achieve low-carbon transformation. For specialized, refined, distinctive, and innovative SMEs, provide additional policy incentives such as targeted subsidies for R&D and market expansion to accelerate their growth into "small giant" enterprises.

5.2.2 Building an Energy Supply System and Formulating Differentiated Energy Management Strategies

1) Accelerate the pace of energy structure upgrading

Accelerate the pace of energy structure adjustment and increase support for new energy, energy conservation, and environmental protection sectors. For example, establish special funds to support new energy technology R&D and application promotion, encourage enterprises to actively participate in new energy project construction, and increase the proportion of non-fossil energy used in modern manufacturing to meet the demands of low-carbon transformation.

2) Optimize Differentiated Energy Efficiency Management Strategies

Further refine energy management strategies tailored to different industries. For the chemical raw materials and chemical products manufacturing sector, prioritize strengthening energy audits and energy-saving retrofits, promoting the adoption of advanced energy-saving technologies and equipment to gradually reduce reliance on fossil fuels. For the electromechanical industry, while continuing to invest resources in improving energy efficiency, develop incentive measures to encourage energy efficiency competitions among enterprises, accelerating their progress in enhancing energy efficiency. For the automotive manufacturing sector, beyond optimizing battery production processes in new energy vehicle manufacturing and promoting energy-saving technologies in traditional fuel vehicle production, planning and construction of new energy vehicle charging infrastructure should be strengthened to ensure the widespread adoption of new energy vehicles. For the electronics manufacturing sector, while focusing on energy management in chip manufacturing and data centers, comprehensive energy management across the entire production process should be enhanced. This includes real-time monitoring and control of electronic equipment energy consumption to reduce overall energy use and carbon emissions.

3) Strengthen R&D and Application of Energy Efficiency Management Technologies

Increase efforts in R&D and application of energy management technologies. Encourage research institutions and enterprises to collaborate on developing more efficient and intelligent energy management systems. For example, leverage IoT technology for real-time monitoring and remote control of energy usage, and utilize big data analytics to provide enterprises with energy optimization recommendations. This will help businesses better manage energy, improve utilization efficiency, and reduce carbon emissions.

5.2.3 Focus on Core Technologies to Drive Innovation in Manufacturing

1) Intensify Research on Core Technologies for Beijing's Key Industries

When focusing on key core areas, efforts should be tailored to the realities of Beijing's modern manufacturing sector to intensify research on core technologies in key industries. For instance: - Addressing low energy efficiency in chemical raw materials and chemical product manufacturing by enhancing R&D on relevant production technologies to improve energy utilization. - Accelerating R&D on core technologies for new energy vehicles—such as battery technology and autonomous driving systems—to meet the transformation needs of the automotive manufacturing sector. - Strengthening R&D on chip manufacturing technologies and AI algorithm optimization to alleviate energy consumption pressures in the electronics manufacturing industry.

2) Strengthening the Integration of Frontier Field Development with Beijing's Industries

When proactively positioning in frontier fields, consideration should be given to integrating these cutting-edge technologies with Beijing's modern manufacturing. In quantum communication, explore applications for enhancing information transmission and security in modern manufacturing; in 6G, investigate how 6G technology can boost production efficiency and intelligence levels; in neuroscience, examine how findings can inform human resource management and employee training within modern manufacturing.

5.2.4 Innovate Technologies Based on Industry Characteristics to Enhance Technology Transfer Efficiency

1) Aligning Technology Transfer with Beijing's Industrial Needs

Guided by the principles of green and low-carbon development in modern manufacturing, enhance the targeted nature of scientific research and technology transfer to ensure alignment with Beijing's low-carbon development needs in modern manufacturing. Focus on developing and transferring technologies specifically addressing the weak links in low-carbon development within modern manufacturing sectors (such as the chemical manufacturing industry), ensuring their effective application.

2) Strengthen and Improve Industry-Academia-Research Collaboration Mechanisms

Further strengthen and refine industry-academia-research collaboration mechanisms. The government should introduce more incentive policies to encourage enterprises to establish longer-term, stable partnerships with universities and research institutions. For example, beyond providing subsidies for collaborative projects or offering necessary venues and equipment, a dedicated industry-academia-research cooperation fund could be established to support R&D and technology transfer for collaborative initiatives. Concurrently, enhance management and oversight of these collaborative projects to ensure smooth progress and deepen the breadth and depth of cooperation.

3) Optimizing the Process and Measures for Commercializing Research Outcomes

Optimize the process and measures for technology transfer. After acquiring technological innovations, enterprises should establish a comprehensive technology transfer mechanism encompassing evaluation of the outcomes, formulation of transfer plans, monitoring of the transfer process, and assessment of transfer effectiveness. For instance, when utilizing technological innovations from universities and research institutions, enterprises should first evaluate their feasibility and application value, then develop corresponding transformation plans. Monitoring should be conducted throughout the transformation process to ensure smooth execution, followed by an assessment of outcomes to summarize lessons learned and inform future technology transfer efforts.

References

[1] Ni, H., Qian, P., & Han, D. (2025). The development foundation, major challenges, and strategic thinking for the manufacturing industry during the 15th Five - Year Plan period. Economic Review Journal, (06), 13–25. https://doi.org/10.16528/j.cnki.22 - 1054/f.202506013

[2] Zhang, X., Zhang, Y., Duan, X., et al. (2025). The internal logic and practical path of new quality productive forces enabling the green economy. Journal of Wuhan University of Technology (Social Sciences Edition), 38(05), 65–75.

[3] Jiao, F., & Liu, J. (2025). Artificial intelligence, digital - real technology integration, and the resilience of the manufacturing industry chain. Journal of Yunnan Minzu University (Philosophy and Social Sciences Edition), 42(06), 86–99. https://doi.org/10.13727/j.cnki.53 - 1191/c.20251027.002

[4] Wang, X., Zhu, G., & Zhang, Z. (2025). Digital industry agglomeration and new quality productive forces in manufacturing. Research on Economics and Management, 46(11), 59–77. https://doi.org/10.13502/j.cnki.issn1000 - 7636.2025.11.004

[5] Liu, Y., Xia, J., & Li, Y. (2017). Producer services agglomeration and manufacturing upgrading. China Industrial Economics, (07), 24–42. https://doi.org/10.19581/j.cnki.ciejournal.2017.07.002

[6] Zhao, C. (2021). Digital development and servitization transformation: Evidence from listed manufacturing companies in China. Nankai Business Review, 24(02), 149–163.
[7] Li, C., Li, D., & Zhou, C. (2020). The mechanism of digital economy driving manufacturing transformation and upgrading: An analysis based on the industrial chain perspective. Commercial Research, (02), 73–82. https://doi.org/10.13902/j.cnki.syyj.2020.02.008
[8] Shao, S., & Xu, J. (2023). "Green + Smart Manufacturing" empowering high - quality development of advanced manufacturing. People's Forum · Academic Frontiers, (17), 25–36. https://doi.org/10.16619/j.cnki.rmltxsqy.2023.17.003
[9] Jiao, F., & Zhang, D. (2024). A study on the mechanism of developing strategic emerging industries and future industries to accelerate the formation of new quality productive forces. Journal of Hunan University of Science & Technology (Social Sciences Edition), 27(01), 110–116. https://doi.org/10.13582/j.cnki.1672 - 7835.2024.01.014
[10] National Manufacturing Strategy Advisory Committee. (2018). China Manufacturing 2025 Blue Book. Publishing House of Electronics Industry.
[11] Fang, J., & Wang, K. (2024).Annual report on China's carbon market and green low - carbon economic development. Social Sciences Academic Press.
[12] Mu, S., Yang, B., Zhao, J., et al. (2024).Annual report on Beijing's urban development. Social Sciences Academic Press.
[13] The People's Government of Beijing Municipality. (2022).Implementation plan for carbon peaking in Beijing: Jing Zheng Fa [2022] No. 31[Policy document]. Retrieved December 1, 2025, from https://www.beijing.gov.cn
[14] Beijing Municipal Economy and Information Technology Bureau. (2022).Action plan for green and low - carbon development of the manufacturing industry in Beijing during the "14th Five - Year Plan" period: Jing Jing Xin Fa [2022] No. 42[Policy document]. Retrieved December 1, 2025, from https://www.beijing.gov.cn
[15] Beijing Municipal Headquarters of the People's Bank of China, China Banking and Insurance Regulatory Commission Beijing Bureau, China Securities Regulatory Commission Beijing Bureau, et al. (2021).Opinions on supporting green and low - carbon high - quality development in Beijing with finance: Yin Guan Fa [2021] No. 102[Policy document]. Retrieved December 1, 2025, from https://www.beijing.gov.cn
[16] Beijing Municipal Commission of Development and Reform, Beijing Municipal Science & Technology Commission. (2020). Implementation plan for building a market - oriented green technology innovation system in Beijing: Jing Fa Gai [2020] No. 789[Policy document]. Retrieved December 1, 2025, from https://www.beijing.gov.cn
[17] The People's Government of Beijing Municipality. (2024). Measures for the administration of carbon emission trading in Beijing: Jing Zheng Fa [2024] No. 6[Policy document]. Retrieved December 1, 2025, from https://www.beijing.gov.cn

[18] Beijing Municipal Commission of Development and Reform, Beijing Municipal Finance Bureau, Beijing Municipal Environmental Protection Bureau. (2013).Measures for the administration of cleaner production: Jing Fa Gai Gui [2013] No. 6[Policy document]. Retrieved December 1, 2025, from https://www.beijing.gov.cn
[19] The People's Government of Beijing Municipality. (2021).The 14th Five - Year Plan for ecological and environmental protection in Beijing: Jing Zheng Fa [2021] No. 35[Policy document]. Retrieved December 1, 2025, from https://www.beijing.gov.cn
[20] Beijing Municipal Bureau of Statistics & NBS Survey Office in Beijing. (2012).Notice on implementing the new statistical classification for modern manufacturing and other emerging industries (Jing Tong Fa [2012] No. 43)[Circular].
[21] Feng, X. (2024).Research on the impact of digital transformation in manufacturing on carbon emissions[Master's thesis, Hebei GEO University]. https://doi.org/10.27752/d.cnki.gsjzj.2024.000061
[22] Fan, Y., Liu, L. C., Wu, G., et al. (2006). Analyzing impact factors of CO2 emissions using the STIRPAT model. Environmental Impact Assessment Review, 26(4), 377–395.
[23] Wang, C., & Yuan, X. (2025). How can intelligent manufacturing empower China's industrial green and low - carbon transformation? Hainan Finance, (02), 3–17.
[24] Feng, J. (2024). Research on the new energy industry enabling green and high - quality development. Trade Fair Economy, (24), 133–136. https://doi.org/10.19995/j.cnki.CN10 - 1617/F7.2024.24.133