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Exploring Carbon Emission Peak and Reduction Strategies in China's Industrial Sector: A Case Study of Wuxi City

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Abstract

As the world's largest manufacturing country, China's industrial carbon emission reduction is crucial to achieving its "dual carbon" goals. This paper takes Wuxi, a national low-carbon pilot city in Jiangsu Province, as a case, using a bottom-up factor decomposition model to study industrial carbon peak prediction and sector-specific emission reduction strategies. Results show that under the usual-growth scenario (UG), Wuxi's industrial emissions keep growing and will not peak before 2030, reaching 122.18 million tCO_2 that year. Under the emission-controlled scenario (EC), with industrial structure optimization and energy intensity control, emissions peak in 2026 at 100.55 million tCO_2, 17.7% lower than the baseline. The reinforced-mitigation scenario (RM), combining in-depth structural adjustment and technological upgrade, sees the peak in 2025 at 94.22 million tCO_2, a 22.9% reduction. It is necessary to implement differentiated emission reduction strategies, focusing on high-emission and low-carbon productivity industries such as electricity and heat production, and ferrous metal smelting and rolling. Through precise management and control, the overall emission reduction efficiency can be improved, providing a reference paradigm for the low-carbon transformation of similar industrial cities.

Keywords: carbon emission peak; reduction strategies; industrial sectors; carbon productivity; China

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1. Introduction

As the world's largest carbon emitter, the Chinese government explicitly committed in the U.S.–China Joint Statement on Climate Change to "peak carbon dioxide emissions around 2030" and has reiterated this goal on multiple international occasions, which has gained widespread recognition from the international community. Achieving this commitment not only relies on advanced emission reduction technologies but also demands systematic research on carbon peak trend prediction and mitigation strategies [1,2]. The industrial sector, as the core source of carbon emissions in China, accounts for over 70% of the national total emissions. Its carbon peaking process directly determines the realization path of the country's overall emission reduction targets and serves as a key area for formulating mitigation strategies [3–5]. Therefore, research on China's industrial carbon peaking goals and emission reduction strategies holds significant theoretical and practical importance.

Industrial carbon emissions have long been a hot topic in the field of energy economics [6–8]. Scholars have analyzed the driving mechanisms of industrial carbon emissions, predicted peak trends, evaluated emission reduction potentials, and proposed policy

recommendations using various models. For instance, Ang et al. [9–12] employed decomposition analysis to study carbon emissions across four energy types and eight sub-sectors in China's industrial sector, revealing that industrial added value and energy intensity are the primary positive and negative factors affecting carbon emissions, respectively. Wang F. et al. [13] verified through a two-step decomposition method that per capita GDP growth is the core driver of increasing carbon emissions, while the decline in industrial energy intensity is critical for emission reduction. Guo J. [14] further identified, using the modified Laspeyres index decomposition method, that the petroleum, power, coal, and metallurgical industries are key areas for industrial emission reduction. Additionally, Guo C.X. [15] estimated industrial emission reduction potential and its impact on peaking from the dual perspectives of structural and intensity-based emission reduction via economic accounting methods. Wang Y. [16], based on an extended STIRPAT model, found significant differences in emission reduction potentials among sub-sectors within the industrial sector, emphasizing the need for differentiated policies. Wang F. [17] constructed a multi-objective, multi-constraint input–output model, confirming that carbon emission performance standards (CEPT) exert a suppressive effect on high-carbon industries and a promotional effect on low-carbon ones. In comparison to traditional macro-level analyses of total carbon emission reductions [18,19], these bottom-up decomposition analysis methods can better reveal the emission reduction potential of industrial carbon emissions. However, they still lack in-depth micro-case studies on industrial carbon emissions at the provincial or prefecture-level, making it difficult to support local emission reduction practices.

Scholars have conducted in-depth research on industrial sub-sectors with high-emission characteristics using scenario analysis. Wang et al. [20] designed three scenarios for the steel industry using LEAP software and evaluated the feasibility of different pathways by combining emission reduction costs. Li et al. [21] predicted through the IPSO-BP model that if the cement industry implements capacity reduction and new dry-process technologies, its carbon peak could be advanced by 19 years compared to the baseline scenario, reaching the peak before 2030. Lu et al. [22] confirmed, using a PSO-optimized BP neural network model, that the heavy chemical industry can achieve peak emissions under preset mitigation scenarios. Zheng B. et al. [23] constructed carbon emission prediction models for the power industry under scenarios with and without peak targets through time-series analysis and proposed future emission reduction plans for the sector. Yang J.M. et al. [24] demonstrated in their study on the papermaking industry that optimizing energy structure and increasing wastepaper recycling rates can effectively reduce carbon emissions. Zhang et al. [25] estimated, based on the LMDI model, that the non-ferrous metal industry has emission reduction potentials of 858.47 million tons and 1.38465 billion tons under stable and active mitigation scenarios, respectively, and suggested formulating industry-specific policies. Ren and Wang et al. [26] indicated through three scenarios (ES, RHS, CP) designed with the ICEEH model that the power industry should increase investment in renewable energy while restricting new capacity in high-carbon industries such as cement, steel, and ceramics. Despite progress in sub-sector research, existing emission reduction measures remain fragmented, lacking systematic comparison and classification, which impede the formulation of implementable comprehensive strategies [27]. Given the significant differences in carbon emission scales and carbon productivity among industrial sub-sectors, formulating differentiated emission reduction policies has become an urgent priority.

Jiangsu Province is an economically developed eastern province in China, which has taken a leading role in addressing climate change by exploring pathways for achieving provincial carbon peak. Wuxi is the first low-carbon pilot city in Jiangsu Province, which is located in the core area of the Yangtze River Delta urban agglomeration. As an economically developed city, it faces the dual challenges of economic development and energy

conservation/emission reduction due to the high proportion of traditional industries such as power, steel, and petrochemicals. Based on this, this study takes the industrial sector of Wuxi, a national low-carbon pilot city, as the research object to analyze its current carbon emission status, predict peak trends under different scenarios, and propose differentiated emission reduction strategies for various sub-sectors, aiming to provide references for industrial low-carbon transformation in similar cities.

2. Analysis of Carbon Emission Decomposition in the Industrial Sector

The industrial sector in this article does not include mining and construction industry, so carbon emissions in the industrial sector mainly include three types: fossil fuels consumption in the manufacturing industries, industrial electricity power consumption, and thermal consumption. Then, based on the IPCC guidelines [28], the carbon emission inventory of the industrial sectors was calculated.

2.1. Carbon Emissions from Fossil Fuels in the Industral Sectors

Based on the Energy Purchase and Consumption and Inventory Table of Industrial Enterprises, the consumption of raw coal, washed coal, other washed coal, coke, natural gas, liquefied natural gas, diesel, and fuel oil in various manufacturing industries are calculated. Then, the industry inventory includes 30 sub-sectors, which are divided into 9 major sectors based on the natural similarity, including food and beverage and tobacco manufacturing, textile and leather products, papermaking and wood processing, chemical and petroleum processing, non-metallic mineral products, black metal smelting and rolling processing, automotive general and specialized device manufacturing, transportation and electrical and electronic device manufacturing, and other manufacturing (Table 1).

Table 1. Carbon emissions size and its proportion from fossil fuels of the industrial sectors in Wuxi City.

Sectors	2015		2016		2017		2018	
	tCO_2	%	tCO_2	%	tCO_2	%	tCO_2	%
Food and beverage and tobacco manufacturing	69,092	0.2%	69,503	0.2%	46,219	0.2%	39,782	0.1%
Textile and leather products	2,121,876	6.8%	2,031,725	6.7%	1,828,943	6.4%	871,903	3.1%
Papermaking and wood processing	738,548	2.4%	707,973	2.3%	670,612	2.3%	558,558	2.0%
Chemical and petroleum processing	5,322,032	17.0%	6,021,216	19.9%	5,255,859	18.4%	5,182,110	18.3%
Non-metallic mineral products	2,725,819	8.7%	2,484,154	8.2%	2,192,277	7.7%	2,262,827	8.0%
Black metal smelting and rolling processing	17,173,691	55.0%	16,644,112	54.9%	16,495,816	57.7%	17,496,594	61.8%
Automotive and general and specialized device manufacturing	412,095	1.3%	400,809	1.3%	419,614	1.5%	448,423	1.6%
Transportation and electrical and electronic device manufacturing	1,093,209	3.5%	506,712	1.7%	430,154	1.5%	287,864	1.0%
Other manufacturing	1,594,440	5.1%	1,452,928	4.8%	1,269,816	4.4%	1,146,274	4.1%
Total	31,250,802	100.0%	30,319,132	100.0%	28,609,310	100.0%	28,294,336	100.0%

2.2. Carbon Emissions from Electricity and Thermal Consumption in Industrial Enterprises

Based on the analysis table of the electricity consumption form the power supply company, calculate the carbon emissions of the industrial electricity power (Table 2). Based on the industrial thermal consumption data in the Energy Purchase & Consumption and Inventory Table of Industrial Enterprises, calculate the thermal carbon emissions of industrial users (Table 3).

Table 2. Carbon emissions from electricity power of industrial enterprises in Wuxi City.

Year	Total Electricity Consumption/10,000 Kilowatt Hours	Industrial Electricity Consumption/10,000 Kilowatt Hours	Carbon Emissions from Industrial Enterprises/tCO_2
2015	6,005,026	4,746,971	32,417,065
2016	6,386,721	4,957,808	33,856,871
2017	6,866,704	5,269,505	35,985,450
2018	7,328,121	5,543,489	37,856,486

Table 3. Carbon emissions from thermal production of industrial enterprises in Wuxi City.

Year	Industrial Thermal Energy Consumption/GJ	Carbon Emissions from Thermal Production/tCO_2
2015	67,205,827	7,392,641
2016	75,474,655	8,302,212
2017	81,461,659	8,960,782
2018	89,819,476	9,880,142

2.3. Total Carbon Emissions in the Industrial Sectors

Based on the correlation between the above fields and statistical data, carbon emissions of the industrial sector in Wuxi City from 2015 to 2018 are calculated in Table 4. Since the end of the 12th Five Year Plan period, carbon emissions of the industrial sector have shown a continuous growth trend, with a growth rate of 6.99% in 2018 compared to 2015, and an average annual growth rate of 2.28%. By analyzing carbon emission structure in the industrial sector, the carbon emissions in 2018 were 76.0212 million tons of CO_2, of which 28.2943 million tons of CO_2 were emitted from fossil fuels consumption in the manufacturing industry, accounting for 37.2% of the total emissions. The carbon emissions from industrial electricity consumption are 37.8565 million tons of CO_2, accounting for 49.8% of the total emissions. The carbon emissions from thermal consumption are 9.8801 million tons of CO_2, accounting for 13.0% of the total emissions. By analyzing changing trends, the carbon emissions from fossil fuels in the manufacturing industry have gradually decreased, accounting for 37.2% in 2018 from 44.0% in 2015, while the electricity and thermal consumption has gradually increased. In 2018, the carbon emissions from electric and thermal consumption reached 62.8%. It is shown that the manufacturing industry in Wuxi has gradually shifted from traditional fossil fuels to electric and thermal energy as the main source.

Table 4. Carbon emissions and its proportion of the industrial sectors in Wuxi City.

Category	2015		2016		2017		2018	
	tCO_2	%	tCO_2	%	tCO_2	%	tCO_2	%
Fossil fuels	3125.08	44.0%	3031.91	41.8%	2860.93	38.9%	2829.43	37.2%
Electricity power	3241.71	45.6%	3385.69	46.7%	3598.54	48.9%	3785.65	49.8%
Thermal consumption	739.26	10.4%	830.22	11.5%	896.08	12.2%	988.01	13.0%
Total	7106.05	100%	7247.82	100%	7355.55	100%	7603.10	100%

3. Prediction of Carbon Emissions Peak in the Industrial Sector

Decomposition analysis is a very good method that can not only explain the trajectory of carbon emissions but also predict the peak of future carbon emissions [29–31]. It can

avoid the invalidity caused by multicollinearity between elements in multivariate statistical analysis [32].

3.1. Prodicition Methods

Based on decomposition analysis of industrial carbon reduction research in China, the driving forces are confined to several conventional factors, including emission factors, energy intensity, industrial structure, and output size [33,34]. By analyzing the influencing factors on carbon emissions of the industrial sector, set different conditions for each influencing factor, combine various influencing factors, and design three carbon emission scenario in the future, namely the usual-growth scenario (UG), the emission-controlled scenario (EC), and the reinforced-mitigation scenario (RM). In this article, the analysis framework for carbon emission of the industrial sector is shown in Figure 1.

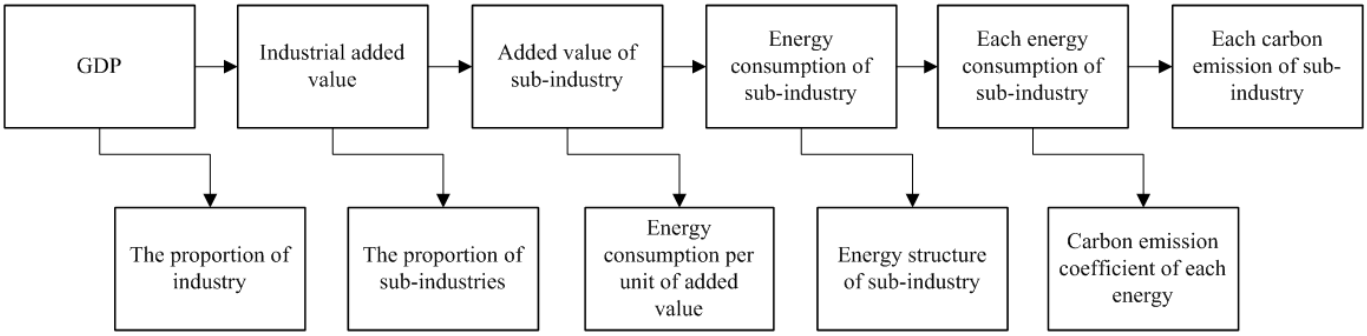


Figure 1. Analysis framework of carbon emission peak in the industrial sector.

Firstly, set the proportion of industrial added value in GDP, which should consider that the industrial proportion must be less than the proportion of secondary industry, excluding the construction industry added value, as well as the growth rate of industrial added value (slightly less than the overall GDP growth rate). Then, decompose the industrial structure and estimate the proportion of each sub-industry; the assumption of the proportion of added value in sub-industries considers the relevant growth targets set in the industry development plan and the direction of overall industrial structural adjustment. Further, calculate the unit added energy consumption of each sub-industry based on historical data and set the rate of energy consumption intensity decrease for each sub-industry based on the overall industrial energy consumption intensity reduction target and industry planning. Moreover, based on the direction of energy structure adjustment and coal control targets formulated by macro policies, set the energy structure changes for each sub-industry. Finally, based on the CO_2 emission factors of different types of energy consumption, calculate the CO_2 emissions of each sub-industry in the industry. Based on the above steps, industrial carbon emissions and related influencing factors can be expressed as follows:

$$P = GDP \times A \times B \times C \times D \times E \quad (1)$$

P is the carbon emissions in the industrial sector, A is the proportion of industrial added value to GDP, B is sub-structure within the industrial sector, C is the energy consumption intensity, D is the energy structure, and E is the carbon emission coefficient.

3.2. Influencing Factors

(1) Economic structure. The most likely change trend is A, which indicates an increase in the proportion of the service sector and a decrease in the proportion of the industry sector.

(2) Sub-structure within the industrial sector. There may be two change trends: One is B1, that is, the optimization and adjustment of the internal structure in the manufacturing industry. According to the trend of economic development, based on the average proportion of industrial added value in various sub-industries within the manufacturing industry, predict the industrial added value by sub-industries in the future. From 2019 to 2030, based on the historical trends of various industries in the manufacturing industry, the proportion of traditional high-energy-consuming industries such as chemical and petroleum processing, black metal smelting and rolling processing, and non-metallic mining and selection will be gradually reduced, and the proportion of strategic industries such as transportation and electrical and electronic information device manufacturing, as well as automotive and general and specialized device manufacturing will be gradually increased. The other is B2, enhancing the optimization and adjustment of the internal structure in the manufacturing industry, that is, based on B1, increasing the intensity of the internal structure adjustment of the manufacturing industry.

(3) Energy consumption intensity. C1 is the decrease rate of energy consumption per unit of industrial added value. The setting should take into account two factors: the first is the rate of decline in energy consumption per unit of GDP in the city, with a preset decline range of 15–18% during 2019~2030, and an average annual decline level ranging from 3.2 to 4.0%; the second is to combine the current data and decline rate of energy consumption per unit of industrial added value in various industries within the manufacturing industry in recent years, and set the basic decline rates of energy consumption per unit of industrial added value in each industry during the 13th Five Year Plan, 14th Five Year Plan, and 15th Five Year Plan, respectively. C2 is the rapidly decreasing rate of energy consumption per unit of industrial added value, that is, based on C1, accelerating the decrease rate of industrial added value per unit in various manufacturing industries from 2019 to 2030, especially in traditional heavy chemical industries such as petrochemicals, ferrous metal smelting, and non-metallic mineral products.

(4) Energy structure. The likely trend is D, that is, optimization of energy structure. Accelerating the development of new energy, fully utilize the advantages of regional lighting and terrain, and develop photovoltaic and wind power new energy. Firstly, it is expected that during the 14th and 15th Five Year Plans, a new grid connection scale of 450 MW will be added for photovoltaic power generation, 400 MW for wind power generation, and 50 MW for resource utilization generator assembly. Secondly, the construction of smart grids will be accelerated.

(5) Other energy-saving and emission reduction measures. There are two trends: E1 is energy-saving and emission reduction measures. From 2019 to 2030, steel, chemical, machinery manufacturing, and other enterprises will adopt multiple technologies such as frequency conversion speed regulation energy-saving technology, air compressor waste heat recovery technology, and enterprise energy control systems to reduce carbon emissions in the city. Meanwhile, accelerate the shutdown and transformation of coal-fired small units in the power industry, build new ultra supercritical gas units, and improve the energy efficiency level of power generation. In the later period, it is expected that the emission factor indicators of the power grid have slightly decreased. E2 is enhancing energy-saving and emission reduction measures, which is based on E1, implying more effective energy-saving and emission reduction measures.

3.3. Scenarios and Results

Based on the scenario analysis of the influencing factors on carbon emissions of fossil fuels consumption, as well as the electricity and thermal consumption in industrial enterprises, carbon emissions peak of the industrial sector are predicted in three scenarios.

(1) The Usual-Growth Scenario (UG)

In this scenario, all influencing factors change according to the growth rate at the last year of the 12th Five Year Plan and the first year of the 13th Five Year Plan. From 2019 to 2030, GDP will be set based on the economic growth rate during 2015~2018 year, while the industrial structure remains unchanged in 2018. The internal structure of the manufacturing industry remains unchanged, and the energy consumption per unit output value is calculated based on a decrease rate during the 13th Five Year Plan period. The energy consumption per unit of industrial added value is set based on the decline rate of the manufacturing industry during 2015–2018, and the decline rate remained unchanged in the future, not considering the disturbance effects of major power projects, energy structure optimization, and energy-saving and emission reduction measures. The result is that under the UG scenario, carbon emissions of the industrial sector have no peak before 2030, with a total carbon emission of 122.18 million tCO_2 in 2030.

(2) The Emission-Controlled Scenario (EC)

In this scenario, the influencing factors change as A + B1 + C1 + D + E1, which are industrial structure optimization adjustment and internal structure adjustment of the manufacturing industry in accordance with economic development trends and industrial policy optimization. The energy consumption per unit of industrial added value is set at three five-year planning periods based on the decline rate of the manufacturing industry from 2015 to 2018, combined with the development of the city's industry. Large gas power projects and new energy projects shall be implemented according to the filing schedule, while at the same time adopting energy-saving and emission reduction policies that are in line with economic development, adjusting and optimizing the energy structure. The electricity and thermal consumption of industrial enterprises is predicted based on the actual development changes in the city, regardless of the scenario. The result is that under the EC scenario, carbon emissions in the industrial sector will peak in 2026, with a total carbon emission of 100.55 million tons of CO_2, which is 17.7% less than the UD scenario.

(3) The Reinforced-Mitigation Scenario (RM)

In this scenario, the influencing factors change as A + B2 + C2 + D + E2, which are industrial structure optimization adjustment and increase in internal structure adjustment changes in the manufacturing industry. Based on the decline rate of manufacturing industry from 2015 to 2018 and combined with the development of the entire city's industries, three five-year planning periods are set for the reduction rate of energy consumption per unit of industrial added value, and efforts are being made to accelerate the reduction rate of energy consumption in industries such as chemical engineering and black metal smelting. Large gas power projects and new energy projects are being accelerated and put into operation ahead of schedule. New photovoltaic and wind power projects will be added during the 14th and 15th Five Year Plans, and more effective energy-saving and emission reduction policies will be implemented. The electricity and thermal consumption of industrial enterprises is predicted based on the actual changes in the city, regardless of the scenario. The result is that in the RM scenario, carbon emissions from the industrial sector will peak in 2025, with a total carbon emission of 94.22 million tCO_2, which is 22.9% less than the UD scenario, as shown in the red circle in

As shown in Figure 2, it can be found that under the UG scenario, the carbon emissions of the industrial sector in Wuxi City cannot reach the peak before 2030. Under the EC scenario, carbon emissions will peak in 2026. Under the RM scenario, carbon emissions will peak in 2025. In the future, if the city is developed under the EC scenario, the total carbon emissions at the peak of 2026 will be 100.55 million tons of CO_2, which is 17.7% less than the UD scenario. If we strengthen the development in the RM scenario, the total carbon

emissions at the peak of 2025 will be 94.22 million tons of CO_2, which is 22.9% less than the UD scenario, as shown in the green circle in Figure 2.

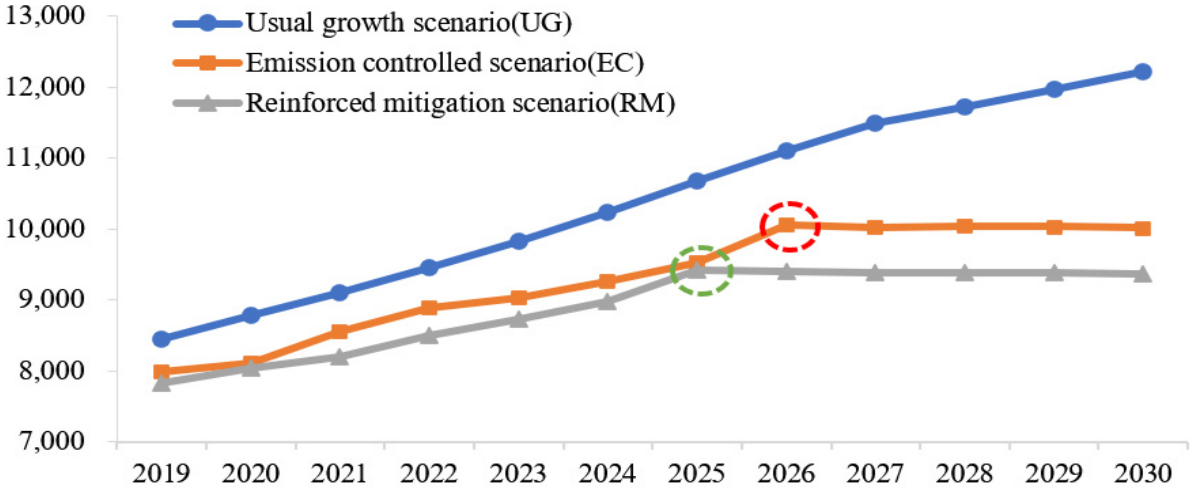


Figure 2. Three scenarios on carbon emissions peak of the industrial sector in Wuxi (10,000 tons).

4. Classification of Carbon Reduction Strategies in Industrial Sectors

Carbon productivity is the economic output level per unit of carbon dioxide, inversely related to the carbon emission intensity, which is per unit of GDP [35–37]. It has two advantages: one is that it can better reflect the differences in carbon emissions between different industrial entities; the other is that it can reflect the changes in industrial growth and carbon emissions. Due to the mutual changes between economic growth and industrial structure, if there is a change in industrial structure, carbon productivity will also undergo corresponding changes. Therefore, the change in this indicator can indirectly reflect the change in industrial structure. Its expression is as follows:

$$\text{Carbon productivity} = \text{Output value}/\text{Carbon dioxide} \quad (2)$$

Based on the amount of carbon emissions and the level of carbon productivity, each sub-industry can be divided into four categories by cross-analysis of emission efficiency and total amount (as shown in Table 5).

1. There are a total of 10 sub-industries in the fourth quadrant (with carbon emissions higher than 100,000 tCO_2 and carbon productivity higher than RMB 200,000 per ton of CO_2), including computer and communication and other electronic device manufacturing; electrical machinery and device manufacturing; textile and clothing; specialized device manufacturing; automobile manufacturing; food manufacturing; general device manufacturing; pharmaceutical manufacturing; metal products; and non-ferrous metal smelting and rolling processing. These sub-industries have a high contribution to national economic growth, as well as a large total amount of emissions and a high level of emission performance. The emissions reduction strategy include improving quality, conducting industry monitoring reports, strengthening carbon intensity control, and strengthening product certification and recognition.

2. There are a total of seven industries in the first quadrant (with carbon emissions less than 100,000 tCO_2 and carbon productivity higher than RMB 200,000 per ton of CO_2), including gas production and supply; furniture manufacturing; comprehensive utilization of waste resources; water production and supply; instrument and meter manufacturing; metal product machinery and device repair; and railway, shipbuilding, aerospace, and other transportation device manufacturing. These sub-industries have a small total emission

and a high level of emission performance, which should be encouraged through control mitigation policy.

3. There are a total of seven sub-industries in the second quadrant (with carbon emissions less than 100,000 tCO_2 and carbon productivity less than RMB 200,000 per ton of carbon dioxide), including alcohol and beverages and tea manufacturing; replication of printing and recording media; agricultural and sideline food processing, manufacturing of cultural, educational, aesthetics, sports and entertainment device; wood processing and wood, bamboo, rattan, palm, grass products, leather, fur, feathers and their products; footwear industry; and other manufacturing industries. Although the total emissions of such sub-industries are small and their emission performance level is also not high, the industrial policy should be strengthened, carbon intensity control should be strengthened, and the entry threshold for investment projects should be raised.

4. There are a total of nine sub-industries in the third quadrant (with carbon emissions higher than 100,000 tCO_2 and carbon productivity less than RMB 200,000 per ton of CO_2), including the production and supply of electricity and thermal; black metal smelting and rolling processing; chemical raw material and chemical product manufacturing; petroleum processing and coking; nuclear fuel processing; textile industry; chemical fiber manufacturing; non-metallic mineral products; paper and paper products; and rubber and plastic products. These sub-industries have a large total emissions and low emission performance, which is the key sectors for control. It is suggested to strengthen industrial policy guidance, accelerate industry upgrading and transformation efforts, strengthen the elimination of outdated and excess production capacity, and carry out pilot projects for industry total control and quota trading in the early stage.

Table 5. Cross-analysis of carbon emissions size and carbon productivity in sub-industries.

Types	Large Emissions Size (>100,000 tCO_2)	Small Emissions Size (<100,000 tCO_2)
High carbon productivity (>RMB 200,000/ton of CO_2)	Computer and communication and other electronic device manufacturing Electrical machinery and device manufacturing Textile and apparel industry Specialized device manufacturing Automobile manufacturing Food manufacturing General device manufacturing Pharmaceutical manufacturing Metal products Nonferrous metal smelting and rolling processing Strategy: industry monitoring reports, industry total control and quota trading, and product certification and recognition	Gas production and supply industry Furniture manufacturing Abandoned resources industry's utilization Water production and supply industry Metal products, machinery, and device repair industry Instrument and meter manufacturing Railway, shipbuilding, aerospace, and other transportation device manufacturing Strategy: relaxing control on mitigation policy
Low carbon productivity (<RMB 200,000/ton of CO_2)	Electricity and heat industry Black metal smelting and rolling processing Chemical raw material and chemical products Petroleum processing, coking, and nuclear fuel processing Textile industry Chemical fiber manufacturing Non-metallic mineral products Paper and paper products Rubber and plastic products Strategy: industry upgrading and elimination of outdated production capacity, industry total control and quota trading, and industrial policy guidance	Alcohol and beverage and tea products Printing and recording media products Agricultural and sideline food processing Cultural, educational, artistic, sports, and entertainment products Wood processing and wood, bamboo, rattan, palm, and grass products Leather, fur, feathers, and footwear products Other manufacturing industries Strategy: carbon intensity control, the entry threshold for investment projects, and industrial policy guidance

5. Discussion and Conclusions

5.1. Discussion

This study employs a bottom-up analytical framework to investigate the industrial carbon emission dynamics of Wuxi City, Jiangsu Province—addressing a key limitation of traditional macro-level forecasting models, which often overlook sub-sectoral heterogeneities in industrial systems. By decomposing carbon emissions into micro-level drivers (i.e., industrial added value share, sub-sectoral value proportion, sector-specific energy intensity, energy structure, and emission factors), the study quantifies the contribution of each factor to emission changes, enabling precise identification of critical intervention points. For example, the analysis reveals that Wuxi's industrial energy consumption structure shifted significantly toward secondary energy: the share of electricity and heat consumption increased from 56.0% in 2015 to 62.8% in 2018. This trend highlights the need for coordinated decarbonization in both end-use industries and the power sector—specifically, accelerating renewable energy substitution (e.g., solar and wind power integration) and optimizing the coal-fired power generation mix—to avoid "emission leakage" from direct to indirect sources.

Furthermore, the study's four-quadrant classification method, which cross-references industrial sub-sectors by emission volume and carbon productivity, addresses the inefficiency of one-size-fits-all emission reduction policies [16]. This framework identifies "high-emission, low-carbon productivity" sectors (e.g., electricity and heat production, ferrous metal smelting) as priority targets for intervention, as these sectors account for 68.2% of Wuxi's total industrial emissions but contribute only 23.5% to industrial GDP. Such targeting ensures the efficient allocation of limited emission reduction resources, aligning with the principle of cost-effectiveness in environmental policy.

Compared with existing research, this study holds threefold theoretical and practical value:

1. It quantifies the synergistic effect of "structural adjustment-technological emission reduction," extending theoretical framework [17]. While industrial structure optimization alone reduces emissions by 9.3% under the EC scenario, combining it with 15% energy intensity reduction and 20% clean energy substitution increases the reduction to 17.7%, shortening the peaking cycle by 4 years.

2. It empirically validates the "double-edged sword" of electric heating substitution: while end-use electrification cuts direct industrial emissions by 12.5%, indirect emissions from coal-dominated power generation offset 4.2% of this reduction—supporting scholars' call for "full-chain decarbonization" across energy production and consumption [26].

3. It demonstrates carbon productivity as an actionable policy metric: prioritizing sectors with carbon productivity <RMB 200,000/ton CO_2 achieves 32% of total emission reductions with only 18% of policy costs, providing a solution to the "development-emission reduction" trade-off.

5.2. Conclusions

This study constructs three scenarios—usual growth (UG), emission reduction (EC), and reinforced mitigation (RM)—to forecast Wuxi's industrial carbon peaking trajectory, integrating scenario analysis with sector-specific carbon productivity evaluation. Core findings are synthesized as follows:

- UG Scenario: Without additional policy intervention, industrial carbon emissions will continue to rise, failing to peak before 2030 and reaching 122.18 million tCO_2 that year—exceeding Wuxi's 2030 low-carbon development target by 18.3%.
- EC Scenario: Under moderate policies (e.g., reduction in high-carbon industry share, annual energy intensity improvement), emissions peak in 2026 at 100.55 million tCO_2, a 17.7% reduction from the UG baseline, and remain stable through 2030.

- RM Scenario: With strengthened measures (e.g., high-carbon industry cut, annual energy intensity improvement, renewable energy penetration), the peak advances to 2025 at 94.22 million tCO_2 (22.9% below UG), creating a 5-year window for post-peak emission decline.

These results confirm that targeted policy intervention is critical for industrial decarbonization. For Wuxi, prioritizing "high-emission, low-productivity" sectors and coordinating power-user side decarbonization will be key to achieving early peaking. For similar industrial cities in the Yangtze River Delta, the study's bottom-up framework and carbon productivity-based classification provide a replicable methodology for designing context-adapted emission reduction strategies. Future research could extend this model by integrating social impact assessments (e.g., employment transitions) to enhance policy feasibility.

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References

1. Sinton, J.E.; Fridly, D.G. What goes up: Recent trends in China's energy consumption. *Energy Policy* **2000**, *28*, 671–687. [CrossRef]
2. Sustainable Development Strategy Research Group in Chinese Academy of Sciences. *China Sustainable Development Strategy Report 3 in 2004*; Science Press: Beijing, China, 2005.
3. Lynn, P.; Ernst, W.; Nathan, M. *China's Industrial Sector in an International Context*; Lawrence Berkeley National Laboratory: Berkeley, CA, USA, 2000.
4. Chen, S.Y. Energy consumption, carbon dioxide emissions and sustainable development of China's industry. *Econ. Res.* **2009**, *4*, 41–55.
5. Chen, S.Y. Energy conservation and emission reduction and win-win development of China's industry: 2009–2049. *Econ. Res.* **2010**, *3*, 129–143.
6. Dong, F.; Hua, Y.; Yu, B. Peak Carbon Emissions in China: Status, Key Factors and Countermeasures—A Literature Review. *Sustainability* **2018**, *10*, 2895. [CrossRef]
7. Voltes-Dorta, A.; Perdiguero, J.; Jimenez, J.L. Are car manufacturers on the way to reduce CO_2 emissions? A DEA approach. *Energy Econ.* **2013**, *2*, 77–86. [CrossRef]
8. Ko, F.K.; Huang, C.B.; Tseng, P.Y. Long-term CO_2 emissions reduction target and scenarios of power sector in Taiwan. *Energy Policy* **2010**, *1*, 288–300. [CrossRef]
9. Ang, B.W.; Pandiyan, G. Decomposition of energy-induced CO_2 emissions in manufacturing. *Energy Econ.* **1997**, *3*, 363–374. [CrossRef]
10. Ang, B.W.; Zhang, F.Q.; Choi, K.H. Factorizing changes in energy and environmental indicators through decomposition. *Energy* **1998**, *6*, 489–495. [CrossRef]
11. Ang, B.W.; Zhang, F.Q. A survey of index decomposition analysis in energy and environmental studies. *Energy* **2000**, *5*, 1149–1176. [CrossRef]

12. Ang, B.W. Decomposition analysis for policy making in energy: Which is the preferred method? *Energy Policy* **2004**, *9*, 1131–1139. [CrossRef]
13. Wang, F.; Wu, L.H.; Yang, C. Driving Factors for Growth of Carbon Dioxide Emissions During Economic Development in China. *Econ. Res. J.* **2010**, *2*, 123–135.
14. Guo, J.; Liu, C.X.; Sun, P. Carbon emissions of industrial sectors in China: Influencing factors and emission reduction potential. *Resour. Sci.* **2011**, *9*, 1630–1640.
15. Guo, C.X. Estimation of industrial emission reduction potential in China. *China Popul. Resour. Environ.* **2014**, *9*, 13–21.
16. Wang, Y.; Bi, Y.; Wang, E.D. Scene prediction of carbon emission peak and emission reduction potential estimation in Chinese industry. *China Popul. Resour. Environ.* **2017**, *1*, 131–140.
17. Wang, F.; Gao, C.; Zhang, W. Industrial structure optimization and low-carbon transformation of Chinese industry based on the forcing mechanism of CO_2 emission peak target. *Sustainability* **2021**, *13*, 4417. [CrossRef]
18. Zhou, S.; Wang, Y.; Yuan, Z.; Ou, X. Peak energy consumption and CO_2 emissions in China's industrial sector. *Energy Strategy Rev.* **2018**, *20*, 113–123. [CrossRef]
19. Dhakal, S. Urban Energy Use and Cities CO_2 Emissions in China and Policy Implications. *Energy Policy* **2009**, *11*, 4208–4219. [CrossRef]
20. Wang, K.; Wang, C.; Lu, X. Scenario analysis on CO_2 emissions reduction potential in China's iron and steel industry. *Energy Policy* **2017**, *4*, 2320–2335. [CrossRef]
21. Li, W.; Gao, S.B. Prospective on energy related carbon emissions peak integrating optimized intelligent algorithm with dry process technique application for China's cement industry. *Energy* **2018**, *165*, 33–54. [CrossRef]
22. Lu, C.; Li, W.; Gao, S.B. Driving determinants and prospective prediction simulations on carbon emissions peak for China's heavy chemical industry. *J. Clean. Prod.* **2020**, *4*, 251. [CrossRef]
23. Zheng, B.; Wang, S.; Xu, J.X. A Review on the CO_2 Emission Reduction Scheme and Countermeasures in China's Energy and Power Industry under the Background of Carbon Peak. *Sustainability* **2022**, *14*, 879. [CrossRef]
24. Yang, J.M.; Hua, Y.C.; Ye, J.R.; Xu, S.Y.; Liu, Z.Y. CO_2 Emissions Accounting and Carbon Peak Prediction of China's Papermaking Industry. *Forests* **2022**, *11*, 1856. [CrossRef]
25. Zhang, H.X.; Li, S.B. Research on the Factors Influencing CO_2 Emission Reduction in High-Energy-Consumption Industries under Carbon Peak. *Sustainability* **2023**, *18*, 13437. [CrossRef]
26. Ren, S.Y.; Wang, P.; Lin, Z.W.; Zhao, D.Q. The Policy Choice and Economic Assessment of High Emissions Industries to Achieve the Carbon Peak Target under Energy Shortage-A Case Study of Guangdong Province. *Energies* **2022**, *18*, 6750. [CrossRef]
27. Bian, H.Y.; Meng, M. Carbon emission reduction potential and reduction strategy of China's manufacturing sector. *J. Clean. Prod.* **2023**, *10*, 138718.
28. Kongboon, R.; Gheewala, S.H.; Sampattagul, S. Greenhouse gas emissions inventory data acquisition and analytics for low carbon cities. *J. Clean. Prod.* **2022**, *343*, 130711. [CrossRef]
29. Hoekstra, R.; Van Der Bergh, J. Comparing structural and index decomposition analysis. *Energy Econ.* **2003**, *1*, 39–64. [CrossRef]
30. Hammond, G.P.; Norman, J.B. Decomposition analysis of energy-related carbon emissions from UK manufacturing. *Energy* **2012**, *41*, 220–227. [CrossRef]
31. Mahony, T.O. Decomposition of Ireland's carbon emissions from 1990 to 2010: An extended Kaya identity. *Energy Policy* **2013**, *59*, 573–581. [CrossRef]
32. Diakoulaki, D.; Mandaraka, M. Decomposition analysis for assessing the progress in decoupling industrial growth from CO_2 emissions in the EU manufacturing sector. *Energy Econ.* **2007**, *29*, 636–664. [CrossRef]
33. Xu, S.; He, Z.; Long, R. Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI. *Appl. Energy* **2014**, *127*, 182–193. [CrossRef]
34. Zhang, Y.J.; Da, Y.B. The decomposition of energy-related carbon emission and its decoupling with economic growth in China. *Renew. Sustain. Energy Rev.* **2015**, *41*, 1255–1266. [CrossRef]
35. Chen, W.; Zhu, D.J.; Bai, Z.L. Research on Relationship Between Industrial Carbon Emissions and Carbon Productivity in Shanghai. *China Popul. Resour. Environ.* **2010**, *9*, 24–29.
36. Zhao, G.H.; Gao, W.J. Comprehensive Evaluation of Generalized Carbon-productivity Index in China's Industrial Sector Based on Frontier Analysis Methods. *Chin. J. Manag. Sci.* **2013**, *1*, 31–36.
37. Lu, M.; Wang, X.; Cang, Y. Carbon Productivity: Findings from Industry Case Studies in Beijing. *Energies* **2018**, *11*, 2796. [CrossRef]

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