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The Role of the Carbon Peaking and Carbon Neutrality Policies in the Transformation and Upgrading of the Chinese Manufacturing Sector: A Pathway to Green, Low-Carbon and Sustainable Development

Rola polityki szczytów emisji i neutralności węglowej w transformacji i modernizacji chińskiego sektora produkcyjnego: droga do zielonego, niskoemisyjnego i zrównoważonego rozwoju

Hongbing Shen

Xi'an Jiaotong University, School of Economics and Finance, Xi'an 710061, China
E-mail: xajtshb123@163.com

Abstract
The level of development within the manufacturing sector serves as a vital indicator of China overall strength and international competitiveness. The implementation of the carbon peaking and carbon neutrality policies is instrumental in expediting the transformation and upgrading of manufacturing industries. This paper investigates the effects and underlying mechanisms of this policy on the manufacturing sector's evolution, emphasizing green, low-carbon, and sustainable development. Utilizing econometric methods such as progressive difference-in-difference, mediation, and moderation analysis, our empirical findings reveal several key insights: First, the positive coefficient associated with the carbon peaking and carbon neutrality policies indicates a significant stimulatory effect on the transformation and upgrading of manufacturing enterprises, a conclusion that persists through various robustness tests. Second, green technology innovation emerges as a vital mediating factor in this positive relationship, while the level of policy attention and the classification of enterprises as heavily polluting serve as influential moderating variables. This research contributes valuable insights for enhancing the implementation of carbon-related policies, fostering an experiential foundation for future initiatives, and guiding manufacturing enterprises in their pursuit of effective transformation and upgrading.

Key words: carbon peaking and carbon neutrality policies, manufacturing transformation and upgrading, green low-carbon, sustainable development

Streszczenie
Poziom rozwoju w sektorze wytwórczym jest istotnym wskaźnikiem ogólnej siły Chin i międzynarodowej konkurencyjności. Wdrożenie polityki szczytu emisji dwutlenku węgla i neutralności węglowej jest instrumentalne w przyspieszaniu transformacji i modernizacji przemysłu wytwórczego. W niniejszym artykule zbadano skutki i mechanizmy leżące u podstaw tej polityki w zakresie ewolucji sektora wytwórczego, kładąc nacisk na zielony, niskoemisyjny i zrównoważony rozwój. Wykorzystując metody ekonometryczne, takie jak progresywna analiza różnicy w różnicy, mediacja i moderacja, nasze ustalenia empiryczne ujawniają kilka kluczowych spostrzeżeń: Po pierwsze, dodatni współczynnik związany z polityką szczytu emisji dwutlenku węgla i neutralności węglowej wskazuje na znaczący efekt stymulujący na transformację i modernizację przedsiębiorstw wytwórczych, wniosek, który utrzymuje się w różnych testach solidności. Po drugie, innowacja w zakresie zielonych technologii wyłania się jako istotny czynnik pośredniczący w tej pozytywnej relacji, podczas gdy poziom uwagi polityki i klasyfikacja przedsiębiorstw jako silnie zanieczyszczających służą jako wpływowe zmienne moderujące. Badania te dostarczają cennych informacji na temat usprawnienia wdrażania polityk związanych z emisją dwutlenku węgla, tworzenia empirycznych podstaw dla przyszłych inicjatyw oraz udzielania wskazówek przedsiębiorstwom produkcyjnym w procesie skutecznej transformacji i modernizacji.

Słowa kluczowe: polityka szczytu emisji dwutlenku węgla i neutralności węglowej, transformacja i modernizacja produkcji, zielona gospodarka niskoemisyjna, zrównoważony rozwój

1. Introduction

As the primary driver of the national economy, the transformation and upgrading of the manufacturing sector serve as a crucial pillar in the establishment of a modern industrial system (Li et al., 2024). Moreover, in the context of green transformation and development in developing countries (Shukla, 1995; Bengtsson et al., 2018), the level of manufacturing plays a pivotal role in assessing a country's overall strength and core competitiveness (Song et al., 2023). Particularly, China, renowned as the world's factory, wields a significant influence on the Chinese and global economy through its manufacturing sector (Chen, 2011; Deng et al., 2020). The 20th National Congress Report of the Communist Party of China emphasized the importance of *building a modern industrial system, focusing on the real economy in economic development, promoting new industrialization, accelerating the construction of a manufacturing powerhouse*. Since the advent of the new era, China's manufacturing sector has experienced rapid growth, with the total number of manufacturing enterprises increasing from 326,998 in 2013 to 441,027 in 2022, representing an average annual growth rate of 3.380%. Despite the positive trajectory in manufacturing development, challenges persist, including issues such as the size-strength disparity, limited capacity for independent innovation, irrational industrial combinations, and severe environmental pollution in China's manufacturing sector (Zhou and Zhang, 2024). Particularly in developing countries like China, manufacturing has historically been associated with high investments, pollution, and energy consumption (Shao et al., 2019). It is imperative to expedite the transformation and upgrading of manufacturing enterprises. The transformation and upgrading of the manufacturing sector typically involve two main aspects: the transformation of development modes and structural optimization (Zhang et al., 2021). Development mode transformation entails a shift from factor-dependent, extensive development to innovation-driven, low-carbon development in manufacturing. Structural optimization, on the other hand, aims to promote product upscale and greening, facilitate efficient resource circulation across the entire industry chain, and enhance sustainable development capabilities. Therefore, assessments centered around the transformation and upgrading of manufacturing should consider dimensions such as green, low-carbon initiatives, and sustainable development.

As the carbon peaking and carbon neutrality policies are continuously being enacted and enforced, the manufacturing sector stands out as a sector with high energy consumption and significant carbon emissions (Gu and Lin, 2024). In this light, expediting the transformation and upgrade of manufacturing has become a crucial focal point for achieving the *dual carbon* objectives (Song et al., 2023; Hu et al., 2024). For instance, in 2023, the National Conference on Industry and Information Technology emphatically stressed the need to *vigorously promote new industrialization and implement high-quality development actions focused on key manufacturing sector chains*. Furthermore, in 2024, the State Council issued the *2024-2025 Energy Saving and Carbon Reduction Action Plan*, outlining specific energy-saving and carbon reduction measures for industries such as building materials. Within the context of how carbon peaking and carbon neutrality policies are impacting the transformation and upgrading of manufacturing, it is evident that green technology innovation will play a pivotal role. Recent research indicates that green technology innovation can effectively alleviate pollution emissions and energy consumption (Zheng et al., 2023). Moreover, by catalyzing the production of green products, it can stimulate new market demands that align with consumer preferences for sustainability (Chen and Zheng, 2023). This is of great significance for achieving sustainable development of economic capacity, technological innovation capacity, social development capacity, and ecosystem service capacity. In light of this, how can we measure the transformation and upgrading of the manufacturing sector? How can we assess the impact of carbon peaking and carbon neutrality policies on this transformation? What methodologies can be employed to verify whether green technology innovation exerts a mediating effect between carbon peaking and carbon neutrality policies and the upgrading of the manufacturing sector? Addressing these three questions is crucial for accelerating the shift towards a more advanced manufacturing landscape and promote sustainable development.

Existing research in the academic domain has yielded a rich array of studies on the discussion and measurement of the transformation and upgrading of the manufacturing sector (Hu et al., 2024; Jin, 2020; Zhu and Wang, 2022). Primarily, scholars have predominantly focused on measuring the level of transformation and upgrading of the manufacturing sector from a macro-regional perspective. For instance, Hu et al. (2024) constructed a comprehensive evaluation system of manufacturing sector transformation and upgrading indicators in Jiangxi Province, considering dimensions such as innovation capability, digital transformation, agglomeration level, and green momentum, using the entropy method for measurement. Zhang and Li (2023) established an evaluation system for the transformation and upgrading of the manufacturing sector in the Yangtze River Delta region, focusing on factors such as factor intensity, structural optimization, and value enhancement. Huang and Zhang (2023) calculated the level of transformation and upgrading of the manufacturing sector in Chinese provinces based on variables like labor productivity, R&D structure proportion, new product output proportion, capital intensity, and the proportion of industrial upgrading. A few scholars have also measured the level of transformation and upgrading of manufacturing enterprises from a micro-enterprise perspective. For example, Zhu and Wang (2022), using research data from manufacturing enterprises in Guangdong Province, identified six specific ways for manufacturing enterprises to transform and upgrade, including the introduction of automation, independent R&D, diversified operations, branding, intelligent equipment or industrial robots, establishing sales channels, and improving management models. Zhao et al. (2022) utilized total factor productivity of enterprises to characterize the level of transformation and upgrading of manufacturing enterprises. While the literature predominantly emphasizes the macro-regional level, with few studies exploring the realm of manufacturing enterprises, there is currently a lack of research focusing specifically on measuring the transformation and upgrading of the manufacturing sector from the perspective of low-carbon transformation and sustainable development.

Additionally, a considerable body of literature has explored the influencing factors of the transformation and upgrading of the manufacturing sector. Specifically, from the perspectives of policy and management, Huang and Zhang (2023) found, based on empirical results, that government policy regulation plays a motivational role in the innovative transformation of the manufacturing sector, while obstructing factor-based transformations. Zhao et al. (2022) posited that the central environmental inspection system represents a significant institutional innovation in China's environmental governance, with empirical evidence indicating that it exerts a significant positive impact on the transformation and upgrading of the manufacturing sector. From the viewpoints of factors and costs, Zhu and Wang (2022) discovered that the increase in labor costs substantially elevates the likelihood of enterprises pursuing automation upgrades. Wang et al. (2018) similarly recognized that rising minimum wage levels indirectly induce an industrial upgrading effect, prompting firms to innovate technologically, thus catalyzing the transformation of manufacturing enterprises. Furthermore, Wang and Wang (2017) examined the new opportunities facing China's equipment manufacturing sector amid emerging labor distribution trends, proposing paths for upgrading this industry to transition from mid- to high-end levels, thereby optimizing the entire value chain. From an environmental perspective, Hu et al. (2024) conducted a series of empirical studies demonstrating that constraints on carbon emissions drive the transformation and upgrading of the manufacturing sector through labor productivity and technological innovation. Regarding the factor perspective, Shen and Yang (2024) indicated that the digital economy can facilitate the advanced and rational transformation of the manufacturing sector, while Wu and Guo (2023) similarly argued that data elements empower this transformation and upgrading. Despite the exploration of drivers for the transformation and upgrading of the manufacturing sector from diverse angles—such as policy, environment, and factors—there remains a notable scarcity of literature focusing specifically on the impact effects and mechanisms of carbon peaking and carbon neutrality policies as they pertain to the transformation and upgrading of the manufacturing sector.

In summary, the marginal contributions of this study are as follows: First, it aims to scientifically evaluate the transformation and upgrading of the manufacturing sector. Based on the fundamental connotations and primary objectives of this transformation, the study utilizes data from A-share listed enterprises spanning 2010 to 2023 to conduct a rigorous assessment from the perspectives of green low-carbon development and sustainable development. Second, it seeks to clarify the impact effects and mechanisms of carbon peaking and carbon neutrality policies on the transformation and upgrading of the manufacturing sector. On one hand, a gradual difference-in-difference method is employed to empirically test the specific effects of the implementation of carbon peaking and carbon neutrality policies on manufacturing transformation and upgrading. On the other hand, the framework incorporates elements such as green technological innovation, the degree of government attention, and the extent of corporate pollution, thereby elucidating the specific mechanisms through which carbon peaking and carbon neutrality policies influence the transformation and upgrading of the manufacturing sector.

2. Theoretical Analysis

2.1. Carbon Peaking and Carbon Neutrality Policies and Corporate Transformation and Upgrading

China is currently in an accelerated stage of post-industrialization, where the majority of economic growth models are closely linked to carbon dioxide emissions (Li and Sun, 2024). The government's implementation of carbon peaking and carbon neutrality policies encourages enterprises to engage in low-carbon initiatives and reduce emissions, thereby facilitating sustainable development in both economic and environmental realms (Pu et al., 2024). Given that the low-carbon transformation and upgrading of the manufacturing sector is a crucial component in achieving dual carbon goals (Gu and Lin, 2024), the promulgation and enforcement of carbon peaking and carbon neutrality policies have a distinctly positive impact on promoting the transformation and upgrading of manufacturing enterprises. Specifically, on one hand, the implementation of policy tools such as carbon taxes influences the production decisions of many manufacturing enterprises characterized by high energy consumption and emissions (Li et al., 2022). Such policies increase the direct costs associated with carbon emissions, motivating manufacturing firms to reassess and optimize their production processes, enhance investments in the research and development of low-carbon technologies, and adopt effective energy-saving and emission-reduction measures, thus fostering the green low-carbon development of manufacturing enterprises. To reduce carbon emissions, manufacturing enterprises will actively invest in research and development and improve production processes. Enterprises will increase their research and application of renewable energy utilization technologies and reduce their dependence on traditional fossil fuels. On the other hand, carbon peaking and carbon neutrality policies encourage manufacturing enterprises to actively implement various energy-saving and emission-reduction strategies, utilizing advanced environmental technologies to enhance energy efficiency, lower production costs, and reduce reliance on fossil fuels. This, in turn, elevates their developmental quality and effectiveness. Simultaneously, as manufacturing enterprises respond to carbon peaking and carbon neutrality policies, they significantly meet market demands for low-carbon products, which, to some extent, strengthens their market competitiveness and brand image, ultimately promoting sustainable development within the manufacturing sector. In addition, companies that are the first to achieve low-carbon transformation under the global dual carbon trend have products that better meet the environmental requirements of the international market, can break through green trade barriers, gain more international market share, and enhance their international competitiveness. To promote the achievement of the dual carbon goals, the government will introduce a series of policy support and subsidy measures, such as tax incentives, fiscal subsidies, green finance, etc., to support the low-carbon transformation of manufacturing enterprises and reduce their transformation costs and risks. Manufacturing enterprises will strengthen cooperation with upstream and downstream enterprises to achieve low-carbon goals and jointly promote the greening of the industrial chain. In addition, the products of the enterprises that take the lead in realizing the low-carbon transformation under the global dual-carbon trend are more in line with the environmental protection requirements of the international market, can break through the green trade barriers, gain more international market share, and improve the international competitiveness of the enterprises. In order to promote the realization of the dual-carbon goal, the government will introduce a series of policy support and subsidy measures, such as tax incentives, fiscal subsidies, green finance, etc., to support the low-carbon transformation of manufacturing enterprises and reduce the transformation costs and risks of enterprises. In order to achieve the low-carbon goal, manufacturing enterprises will strengthen the cooperation with upstream and downstream enterprises and jointly promote the greening of the industrial chain.

Based on this, the study proposes the following research hypothesis:

H1: Carbon peaking and carbon neutrality policies have a significant positive impact on the green low-carbon development and sustainable development of manufacturing enterprises, meaning that carbon peaking and carbon neutrality policies exert a notable positive influence on the transformation and upgrading of manufacturing firms.

2.2. Carbon Peaking and Carbon Neutrality Policies, Green Technological Innovation, and the Transformation and Upgrading of the Manufacturing Sector

With the enactment and deepening implementation of carbon peaking and carbon neutrality policies, the intermediary role of green technological innovation in the process through which these policies affect the transformation and upgrading of the manufacturing sector has become increasingly prominent. From the perspective of carbon peaking and carbon neutrality policies' impact on green technological innovation, firstly, as China has explicitly set the goals of reaching peak carbon emissions by 2030 and achieving carbon neutrality by 2060, these policies necessitate the establishment of clear emission reduction targets and timelines. This encourages manufacturing enterprises to enhance production processes and adopt clean energy initiatives, thereby promoting the research, development, and application of green technologies. For instance, the *Guiding Opinions on Accelerating the Green Development of the Manufacturing sector*, jointly issued by the Ministry of Industry and Information Technology, the National Development and Reform Commission, the Ministry of Finance, the Ministry of Ecology and Environment, the People's Bank of China, the State-owned Assets Supervision and Administration Commission, and the State Administration for Market Regulation, emphasizes the establishment of a robust technological, policy, and standard framework to support green development in the manufacturing sector. Secondly, the promulgation and implementation of carbon peaking and carbon neutrality policies can significantly provide support in terms of funding and favorable policies for green technological innovation within manufacturing enterprises, thus mitigating relevant research and development costs and risks. Lastly, these policies can enhance public awareness of environmental protection, encouraging consumers and investors to show a greater preference for green and sustainable products. Consequently, enterprises that engage in green technological innovation can improve their brand image, ultimately attracting more customers and investment.

From the perspective of the impact of green technology innovation on sustainable development of enterprises, green technology innovation has had a significant positive impact on sustainable development through promoting industrial green and low-carbon transformation, promoting the development of emerging industries, enhancing enterprise competitiveness, and promoting regional economic green transformation. These impacts are not only reflected in the speed and quality of economic growth, but also in the improvement of the ecological environment and the enhancement of social welfare. Specifically, green technology innovation can reduce production costs and resource consumption of enterprises, improve production efficiency and product quality, thereby promoting rapid economic growth. At the same time, the promotion and application of green technologies can also reduce environmental pollution and ecological damage, improve the quality and sustainability of the ecological environment. In addition, green technology innovation can also drive the development of related industries and increase employment opportunities, improve social welfare and people's living standards. From the viewpoint of green technological innovation's contribution to the transformation and upgrading of manufacturing enterprises, on one hand, it can lead to increased productivity (Cao et al., 2023). By integrating green production technologies into their manufacturing processes, enterprises can substantially reduce energy consumption and the use of various raw materials, thereby lowering production costs and further enhancing efficiency and environmental sustainability, which is advantageous for the green low-carbon development of manufacturing firms. On the other hand, green technological innovation can facilitate collaboration between enterprises and provide guidance for investment (Cao et al., 2023). As the commitment to green innovation becomes more widespread, many firms are keen to establish cooperative relationships with those possessing green production technologies, collectively investing in various green technology innovations and improvements. This not only aids in resource sharing but also accelerates the application and promotion of advanced green technologies, thereby fostering the sustainable development of manufacturing enterprises.

Based on this, the study proposes the following research hypotheses:

H2: Green technological innovation plays a positive mediating role in the impact of carbon peaking and carbon neutrality policies on low-carbon development.

H3: Green technological innovation serves as a positive mediating factor in the influence of carbon peaking and carbon neutrality policies on sustainable development.

2.3. The Moderating Role of Government Attention

The elevation of government attention is a crucial factor in effectively implementing carbon peaking and carbon neutrality policies. To fully leverage the impact of carbon peaking and carbon neutrality policies on the transformation and upgrading of the manufacturing sector, it is imperative to establish a foundation of heightened government attention. The dual carbon policy and government attention have a significant synergistic effect in promoting the low-carbon transformation of manufacturing enterprises. The dual carbon policy sets clear transformation goals and timelines for enterprises, while government attention provide necessary resources and incentives for enterprises. In regions with higher levels of government attention, the implementation effect of dual carbon policies will be more pronounced, as enterprises can more easily obtain the necessary funding, technology, and policy support, thereby accelerating the process of low-carbon transformation. The moderating role of government attention in influencing the process of manufacturing sector transformation and upgrading under carbon peaking and carbon neutrality policies is primarily achieved through the following avenues: On one hand, it reflects the intensity of government's focus on various demands such as national and public interests, typically conveyed through the level of government attention (Wang et al., 2024). A higher level of government attention signifies stronger governmental demands (Yang, 2020). Therefore, when the government demonstrates a heightened level of concern regarding environmental protection and pollution, it indicates a stronger demand for green and low-carbon initiatives. This, in turn, facilitates the implementation of relevant carbon peaking and carbon neutrality policies, leading to a more pronounced positive impact on the low-carbon transformation of manufacturing enterprises, particularly in reducing carbon dioxide emissions. On the other hand, in situations of elevated government attention, enterprises are inclined to actively respond to governmental calls, cooperating in the implementation of related policies (Wang et al., 2024). This, in turn, enables enterprises to seek governmental resource support, thereby generating a more apparent positive impact on the sustainable development of manufacturing enterprises.

Based on this, the study proposes the following research hypothesis:

H4: Government support has a moderating effect on low-carbon transformation, with regions experiencing higher levels of government support showing a more pronounced effect of carbon peaking and carbon neutrality policies on the low-carbon transformation of manufacturing enterprises.

2.4. The Moderating Role of Heavy Industrial Pollution

Considering the high energy consumption, pollution, and carbon emissions associated with heavily polluting enterprises, the impact of these enterprise characteristics on the regulation of the transformation and upgrading of the manufacturing sector under carbon peaking and carbon neutrality policies is primarily manifested in the following aspects: On one hand, in comparison to other manufacturing enterprises, heavily polluting manufacturing enterprises are more likely to become the focus of relevant governmental supervision. As a result, with the continual advancement of carbon peaking and carbon neutrality policies, the government imposes stricter emission standards and environmental regulations, compelling such enterprises to reduce pollution and carbon emissions. This compels heavily polluting enterprises to take more proactive measures in technological innovation and process reform, reducing their reliance on fossil fuels such as petroleum, in order to achieve higher levels of green and low-carbon development goals. On the other hand, if heavily polluting enterprises fail to take action to reduce their environmental impact, they will find it difficult to achieve sustainable development. Therefore, under the impetus

of carbon peaking and carbon neutrality policies, governmental departments incentivize these industries to adjust their production strategies and improve energy efficiency through mechanisms such as tax incentives, subsidies, and green financing. This, in turn, more effectively promotes the sustainable development of manufacturing enterprises. In heavily polluting enterprises, due to greater environmental pressure, resource efficiency, and market competition challenges, the low-carbon transformation effect of dual carbon policies is often more pronounced. By implementing dual carbon policies, these enterprises can not only reduce their negative impact on the environment, but also improve economic efficiency, enhance market competitiveness, and contribute to achieving sustainable development goals.
Based on this, the study proposes the following research hypothesis:
H5: Enterprise characteristics have a moderating effect on low-carbon transformation. In heavily polluting enterprises, the low-carbon transformation effect of carbon peaking and carbon neutrality policies is more pronounced.

3. Research Design

3.1. Model construction

3.1.1. Baseline model

This study employed the establishment of low-carbon pilot cities as a quasi-natural experiment. Manufacturing enterprises located within these low-carbon pilot cities serve as the treatment group, while those situated outside these cities act as the control group. Thus, a difference-in-differences (DID) model was constructed to examine the impact of carbon peaking and carbon neutrality policies on the transformation and upgrading of the manufacturing sector. Taking sustainable development of manufacturing enterprises as the dependent variable, the specific model is expressed as follows:

$$sgrowth_{it} = \alpha_0 + \alpha_1 did_{it} + \alpha_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

Where, the subscripts *i* and *t* represent cities and years, respectively, *sgrowth* denotes the sustainable development of manufacturing enterprises; $policy_i \times post_t$ denotes the *did* variable, with $policy_i$ being a binary variable (equal to 1 for treatment cities and 0 for control cities) and $post_t$ being a binary variable indicating the time period of policy implementation (equal to 1 for periods when the policy is implemented and 0 otherwise). X represents a set of control variables, while μ_i, λ_t, and ε_{it} denote regional fixed effects, year fixed effects, and the error term, respectively.

3.1.2. Mechanism testing model

Building upon the baseline model and hypotheses 2 and 3, to further explore the transmission mechanism of carbon peaking and carbon neutrality policies in the process of transforming and upgrading the manufacturing sector, we constructed a mediating mechanism testing model using sustainable development of manufacturing enterprises as the dependent variable. The model is represented as follows:

$$green_{it} = \beta_0 + \beta_1 did_{it} + \beta_2 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

$$sgrowth_{it} = \kappa_0 + \kappa_1 did_{it} + \kappa_2 green_{it} + \kappa_3 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{3}$$

Where, *green* represents the intermediary variable (green technology innovation), while μ_i, λ_t, and ε_{it} denote regional fixed effects, year fixed effects, and the error term, respectively.

3.1.3 Moderation testing model

Expanding on the baseline model and hypotheses 4 and 5, to further investigate the moderating effects of variables such as government attention and whether an enterprise is classified as a heavy polluter in the impact of carbon peaking and carbon neutrality policies on the transformation and upgrading of the manufacturing sector, we constructed a moderation mechanism testing model. Using sustainable development of manufacturing enterprises as the dependent variable and government attention as the moderating variable, the model is as follows:

$$sgrowth_{it} = \eta_0 + \eta_1 did_{it} + \eta_2 did_{it} \times gov_{it} + \eta_3 gov_{it} + \eta_4 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{4}$$

Where, *gov* represents the moderating variable (government attention), $did_{it} \times gov_{it}$ is the interaction term between the low-carbon city pilot policy variable and government attention. μ_i, λ_t, and ε_{it} denote regional fixed effects, year fixed effects, and the error term, respectively.

3.2. Variable selection

3.2.1. Dependent variable

The dependent variable in this study is the transformation and upgrading of the manufacturing sector. This transformation was divided into two dimensions: the green and low-carbon development of manufacturing enterprises, and the sustainable development of these enterprises. From the green and low-carbon perspective, the level of development is represented by the ratio of carbon dioxide emissions to total revenue (denoted as *co*) and the ratio of sulfur dioxide emissions to total revenue (denoted as *so*); from the perspective of sustainable development (*sgreen*), the sustainable development data for manufacturing enterprises is sourced from the CSMAR database of sustainable development for Chinese listed enterprises. This data evaluates corporate performance across environmental, social, and financial dimensions, establishing a comprehensive evaluation framework that reflects the effectiveness of enterprises in promoting sustainability, improving livelihoods, and enhancing efficiency. Thus, the sustainable development of manufacturing enterprises was quantified as the sum of environmental sustainability, social sustainability, and financial sustainability.

3.2.2. Core independent variable

The core independent variable of this study is the carbon peaking and carbon neutrality policies, measured through low-carbon pilot cities (denoted as *did*). The constructed model evaluates the impact of low-carbon pilot cities on the transformation and upgrading of the manufacturing sector across urban and year dimensions. Specifically, the low-carbon city pilot initiatives were launched in 2010, 2012, and 2017, encompassing these three batches of pilot cities. Notably, certain cities participated in the pilot twice, while some provinces with second-round pilot cities had previously been included in earlier lists. Following the research of scholars such as Song et al. (2019) and Zhang (2020), this study defined pilot cities with repeated participation according to the earliest implementation date. If a province is designated as a low-carbon pilot area, all cities within that province are considered low-carbon pilot cities.

3.2.3. Mediator variable

The mediator variable in this study is green technology innovation (denoted as *green*). In accordance with the research of Wang and Wang (2021), this variable was quantified by the total number of green invention patents and utility model patents applied for by listed enterprises, with 1 added to this total before taking the natural logarithm.

3.2.4. Moderating variables

The moderating variables in this study are government attention (denoted as *gov*) and whether the enterprise is classified as a heavy polluter (denoted as *polution*). Government attention was quantified through text analysis, specifically by counting the occurrences of relevant keywords in government work reports at the municipal level. These categories include environmental protection, environmental pollution, energy consumption, collaborative development, green production, green living, ecological sustainability, institutional development, among others. Enterprises categorized as heavy polluters are assigned a value of 1, while those not classified as such receive a value of 0.

3.2.5. Control variables

This study selected six control variables: enterprise size (denoted as size), enterprise leverage (denoted as lev), return on assets (denoted as roa), intangible assets (denoted as intangible), firm age (denoted as firmage), and executive compensation (denoted as salary). Specifically, enterprise size is represented by the natural logarithm of total assets at year-end; enterprise leverage is measured as the ratio of total liabilities to total assets; return on assets is represented by the ratio of net profit to total assets; the proportion of intangible assets is captured by the ratio of total intangible assets to total assets; firm age is indicated by the number of years a company has been operating; and executive compensation is represented by the total remuneration of the top three executives at year-end, also subjected to natural logarithm transformation.

3.3. Data description

This data from A-share listed companies from 2010 to 2023 in the CSMAR database. The dataset underwent the following procedures: firstly, only A-share listed enterprises in the manufacturing sector were retained; secondly, enterprises that have been delisted or were previously flagged as ST or *ST were excluded; and finally, incomplete data from listed enterprises was also removed.

4. Empirical Analysis

4.1. Descriptive statistics

Table 1 presents the descriptive statistical results of the variables discussed in this paper, focusing on aspects such as mean, standard deviation, minimum, and maximum values. From Table 1, it is observed that, in terms of mean and standard deviation, the ratio of sulfur dioxide to operating income has the highest mean at 110.57, followed by enterprise size (22.04), executive compensation (15.20), government attention level (8.52), enterprise age (2.87), and sustainable development (2.13). The means of the remaining variables do not exceed 1.00. Regarding the standard deviation of each variable, the ratio of sulfur dioxide to operating income also has the highest standard deviation at 138.27. This indicates that, among all variables, the values of the sulfur dioxide to operating income ratio exhibit the greatest variation from the mean. In contrast, the standard deviations of return on assets and the proportion of intangible assets are the smallest, both not exceeding 0.10, suggesting that the data for these two variables shows the least variation from their respective means.

Table 1. Descriptive Statistics Results

	count	mean	sd	min	max
green	22791	0.716	1.029	0.000	4.307
co	22791	0.517	0.630	0.048	2.805
so	22791	110.573	138.267	1.459	770.491
sgrowth	22791	2.133	22.617	-100.663	149.125
gov	22791	8.518	0.285	7.584	9.516
size	22791	22.037	1.169	19.889	25.626
lev	22791	0.412	0.192	0.057	0.886
roa	22791	0.041	0.065	-0.212	0.216
intangible	22791	0.045	0.035	0.001	0.203
firmage	22791	2.868	0.348	1.386	3.526
salary	22791	15.203	0.772	13.245	17.250

4.2. Correlation analysis

Table 2 illustrates the results of the correlation analysis among the primary variables. As depicted in Table 2, the correlation coefficients among the various control variables generally remain below 0.3, indicating that the model constructed in this study experiences minimal multicollinearity interference. Furthermore, regarding the policy variable, the carbon peaking and carbon neutrality policies exhibit a negative correlation with the ratio of carbon dioxide to revenue in the green low-carbon dimension, which is statistically significant at the 1% level. In contrast, this policy variable shows a notable positive correlation with both the ratio of sulfur dioxide to revenue and the sustainable development dimension.

Table 2. Correlation Analysis Results

	co	so	sgrowth	did	green	gov	polution	size	lev	roa	intangible	firmage	sa-lary
co	1												
so	-0.121***	1											
sgrowth	-0.001	-0.012*	1										
did	-0.245***	0.048***	0.028***	1									
green	-0.129***	-0.262***	0.049***	0.171***	1								
gov	-0.072***	0.435***	0.070***	0.075***	-0.126***	1							
polution	0.752***	-0.088***	0.051***	-0.133***	-0.083***	0.025***	1						
size	0.058***	-0.604***	0.023***	0.075***	0.503***	-0.283***	0.061***	1					
lev	0.160***	-0.355***	0.009	-0.056***	0.231***	-0.201***	0.092***	0.421***	1				
roa	-0.068***	-0.159***	0.004	-0.012*	-0.018***	-0.050***	-0.053***	0.059***	-0.377***	1			
intangible	0.035***	0.027***	-0.005	-0.029***	-0.048***	-0.017**	0.030***	-0.058***	0.035***	-0.085***	1		
firmage	-0.082***	-0.016**	-0.004	0.178***	0.143***	0.006	0	0.218***	0.082***	-0.062***	-0.015**	1	
salary	-0.161***	-0.330***	0.004	0.242***	0.360***	-0.115***	-0.090***	0.541***	0.045***	0.246***	-0.050***	0.266***	1

Note: * and ** represent significance at levels of 10%, 5%, and 1%, respectively.

4.3. Baseline regression analysis

Table 3 presents the baseline regression results on the impact of the carbon peaking and carbon neutrality policies on the transformation and upgrading of the manufacturing sector. According to Table 3, in the context of the green low-carbon dimension of the transformation and upgrading of the manufacturing sector, the coefficients of the carbon peaking and carbon neutrality policies on the ratio of carbon dioxide to revenue and the ratio of sulfur dioxide to revenue are -0.040 and -5.378, respectively, both significant at the 1% level. This indicates that the continued implementation of the carbon peaking and carbon neutrality policies significantly suppresses emissions of carbon dioxide and sulfur dioxide by enterprises, further underscoring its ability to robustly promote positive environmental changes and facilitate the green low-carbon development of enterprises. Firstly, the dual carbon policy encourages enterprises to re-examine their production processes and energy efficiency, promoting the adoption of more energy-efficient and efficient production technologies and equipment. This not only helps reduce the carbon emissions of enterprises, but also improves resource utilization efficiency, reduces resource waste and environmental pollution. Secondly, the dual carbon policy encourages enterprises to increase their investment in green and low-carbon technology research and development, promoting their transformation towards more environmentally friendly and sustainable production models. This transformation not only helps companies improve their environmental performance, but also enhances their market competitiveness and meets consumers' demand for green and environmentally friendly products.

In terms of the sustainable development dimension of the transformation and upgrading of the manufacturing sector, the impact coefficient of the carbon peaking and carbon neutrality policies on the sustainable development of enterprises is 1.574, significant at the 5% level. This suggests that the continued implementation of the carbon peaking and carbon neutrality policies is favorable for the sustainable development of enterprises, likely due to the policy's encouragement of technological innovation and resource conservation by enterprises, thus enhancing their competitiveness and seizing new market opportunities. Firstly, the dual carbon policy encourages enterprises to optimize resource allocation, improve energy efficiency, reduce resource waste and environmental pollution, which directly enhances the economic and environmental performance of enterprises. By adopting more environmentally friendly and low-carbon production methods and technologies, enterprises can reduce production costs, improve product quality and market competitiveness, thereby laying a solid foundation for their sustainable development. Secondly, the dual carbon policy has promoted technological innovation and industrial upgrading of enterprises. In order to achieve emission reduction targets, enterprises need to constantly explore new low-carbon technologies and production models. This not only helps enterprises break through traditional development bottlenecks, but also brings new market space and profit opportunities.

In conclusion, the implementation of the carbon peaking and carbon neutrality policies has promoted the green low-carbon development and sustainable development of manufacturing enterprises, confirming the significant establishments of H1a and H1b. Hence, the carbon peaking and carbon neutrality policies exhibit a clear positive impact on the transformation and upgrading of the manufacturing sector, validating H1.

Table 3. Baseline Regression Results

	(1)	(2)	(3)
	co	so	sgrowth
did	-0.040***	-5.378***	1.574**
	[0.010]	[1.915]	[0.692]
size	0.008	-71.945***	1.072**
	[0.006]	[1.892]	[0.523]
lev	0.088***	-78.076***	1.429
	[0.024]	[6.951]	[1.824]
roa	-0.446***	-235.104***	7.231*
	[0.043]	[13.216]	[4.205]
intangible	-0.158*	-82.887***	2.587
	[0.089]	[28.640]	[8.448]
firmage	-0.039	-26.711***	1.085
	[0.033]	[7.244]	[2.188]
salary	-0.037***	-8.238***	-0.512
	[0.006]	[1.406]	[0.529]
_cons	1.012***	1946.448***	-18.717
	[0.161]	[43.557]	[12.594]
individuals	YES	YES	YES
year	YES	YES	YES
r2	0.869	0.826	0.107
N	22791.000	22791.000	22791.000

Note: Values in parentheses denote standard deviations. * and ** represent significance at levels of 10%, 5%, and 1%, respectively (the same below).

4.4. Robustness checks

To enhance the scientific rigor of the research findings, this study conducted the following robustness checks:

4.4.1. Exclusion of the COVID-19 impact

Table 4 displays the results of the robustness check by excluding the impact of the COVID-19 pandemic. Specifically, some samples from the year 2020 were removed to control for the influence of the pandemic on the results. As indicated in Table 4, under this robustness check, the carbon peaking and carbon neutrality policies still exhibit a significantly negative impact coefficient on the green low-carbon dimension and a positive impact coefficient on the sustainable development dimension, aligning with the findings from the baseline regression analysis.

Table 4. Robustness Check Results – Exclusion of COVID-19 Impact

	(1)	(2)	(3)
	co	so	sgrowth
did	-0.037***	-5.516***	1.036*
	[0.010]	[1.940]	[0.576]
size	0.009	-72.332***	1.401***
	[0.006]	[1.980]	[0.492]
lev	0.103***	-77.178***	1.238
	[0.024]	[7.325]	[1.587]
roa	-0.433***	-234.367***	6.836*
	[0.046]	[14.067]	[3.978]
intangible	-0.194**	-76.650***	4.844
	[0.092]	[29.498]	[8.057]
firmage	-0.043	-26.746***	0.248
	[0.034]	[7.596]	[1.857]
salary	-0.038***	-8.079***	-0.693
	[0.006]	[1.486]	[0.550]
_cons	1.024***	1949.248***	-20.725*
	[0.166]	[45.273]	[11.535]
individuals	YES	YES	YES
year	YES	YES	YES
r2	0.869	0.824	0.122
N	20815.000	20815.000	20815.000

4.4.2. Propensity score matching with difference-in-differences (PSM-DID)

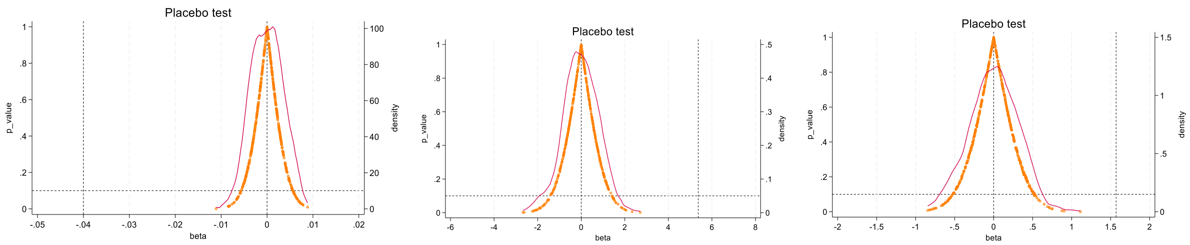
In order to address potential endogeneity issues arising from the differences in characteristics between the listed enterprises in pilot cities and the control group cities, this study presents the results of the robustness check using PSM-DID in Table 5. According to Table 5, the carbon peaking and carbon neutrality policies exhibit significantly negative impact coefficients on carbon dioxide and sulfur dioxide within the green low-carbon dimension, while displaying a positive impact coefficient within the sustainable development dimension. These results are consistent with those obtained from the baseline regression analysis, thereby providing a high degree of robustness to the empirical findings in this paper.

Table 5. Robustness Check Results – PSM-DID Results

	(1)	(2)	(3)
	Co	so	sgrowth
did	-0.041***	-5.280**	1.958***
	[0.011]	[2.072]	[0.737]
size	0.007	-72.031***	0.725
	[0.007]	[2.020]	[0.538]
lev	0.086***	-75.511***	1.594
	[0.026]	[7.394]	[1.960]
roa	-0.467***	-232.570***	7.662*
	[0.048]	[14.486]	[4.627]
intangible	-0.162*	-74.528**	-0.541
	[0.096]	[30.940]	[8.857]
firmage	-0.035	-25.643***	1.237
	[0.036]	[7.678]	[2.293]
salary	-0.032***	-7.790***	-0.438
	[0.007]	[1.490]	[0.556]
_cons	0.983***	1935.382***	-12.780
	[0.174]	[46.166]	[12.654]
individuals	YES	YES	YES
year	YES	YES	YES
r2	0.870	0.826	0.125
N	20279.000	20279.000	20279.000

4.4.3. Placebo test

In order to further eliminate the potential influence of other unknown factors on the transformation and upgrading of the manufacturing sector, thereby confirming that the transformation and upgrading of the manufacturing sector are primarily driven by the implementation of the carbon peaking and carbon neutrality policies, it is necessary to conduct a placebo test. Thus, this study employed a randomized intervention group and control group method. Specifically, during the pilot year, experimental and control groups were randomly assigned, creating virtual low-carbon city pilot policy interaction terms and conducting 500 iterations of sample regressions. If the estimated results remained significant under different hypothetical conditions, it indicated that there might be bias in the original estimates, and the changes in the dependent variables might be influenced by other policy changes or random factors. By observing the P-values and coefficients of the policy interaction terms, it was found that the coefficients of the green low-carbon and sustainable development dimensions significantly deviated from random means, and over 90% of the P-values among the 500 estimated coefficients were above 0.1. Based on this, it can be inferred that the conclusions of this study have passed the placebo test. This implies that the promotion effect of the carbon peaking and carbon neutrality policies on the transformation and upgrading of the manufacturing sector is not incidental, further corroborating the robustness of the baseline results (Figure 1).



(a) Carbon dioxide (b) Sulfur dioxide (c) Sustainable development

Figure 1. Placebo Test of Green Low-Carbon and sustainable development dimensions

4.5. Discussion of mediating mechanisms

In this section, the mediating role of green technology innovation was studied to explore specific influencing mechanisms (refer to Table 6). According to Table 6, the impact coefficient of the carbon peaking and carbon neutrality policies on green technology innovation is 0.042, and it passes the significance test at 5%, indicating that the implementation of the policies would drive the improvement of the level of green technology innovation. Specifically, the elevation of green technology innovation level has a significant push on the carbon dioxide and sulfur dioxide emissions of enterprises, with impact coefficients of -0.037 and -4.562, respectively, passing the significance test at the 1% level. This demonstrates that green technology innovation can significantly promote the green and low-carbon development of manufacturing enterprises. This mechanism can be summarized as follows: the implementation of the carbon peaking and carbon neutrality policies leads to an elevation in the level of green technology innovation, further strengthening the green and low-carbon development of manufacturing enterprises. Moreover, it also has a pronounced positive impact on the sustainable development of manufacturing enterprises, with an impact coefficient of 0.967, also passing the significance test at the 1% level. This mechanism can be summarized as follows: the implementation of the carbon peaking and carbon neutrality policies leads to an improvement in the ability of green technology innovation, further driving the sustainable development of manufacturing enterprises.

Firstly, the improvement of green technology innovation level means that manufacturing enterprises can adopt more environmentally friendly and efficient technologies and equipment in the production process, thereby significantly reducing energy consumption and pollutant emissions. This not only helps enterprises reduce environmental burden and improve environmental performance, but also conforms to the global trend of green and low-carbon transformation, which helps enhance the market competitiveness of enterprises. Secondly, green technology innovation has brought new growth points to enterprises. By developing and promoting green and low-carbon products and technologies, enterprises can open up new market space and meet consumers' demand for environmentally friendly and healthy products. This innovation not only promotes the optimization and upgrading of the enterprise's business structure, but also brings sustained economic benefits and brand value enhancement. More importantly, the improvement of green technology innovation level helps to build the sustainable development capability of enterprises. Through continuous technological iteration and innovation, enterprises can adapt to constantly changing market environments and policy requirements, and maintain long-term competitive advantages. At the same time, green technology innovation can also promote collaborative cooperation between enterprises and upstream and downstream enterprises in the supply chain, jointly promoting the green and low-carbon transformation of the entire industry chain.

In conclusion, green technology innovation plays a significant positive mediating role in the process of driving the transformation and upgrading of the manufacturing sector through the carbon peaking and carbon neutrality policies, thus validating hypotheses 2 and 3.

Table 6. Mediating Effects Results

	(1)	(2)	(3)	(4)
	green	co	so	sgrowth
green		-0.037***	-4.562***	0.967***
		[0.003]	[0.778]	[0.275]
did	0.042**	-0.039***	-5.186***	1.533**
	[0.019]	[0.010]	[1.916]	[0.691]
size	0.370***	0.022***	-70.258***	0.715
	[0.013]	[0.006]	[1.929]	[0.537]
lev	-0.124***	0.084***	-78.643***	1.549
	[0.045]	[0.024]	[6.949]	[1.825]
roa	-0.294***	-0.457***	-236.445***	7.515*
	[0.090]	[0.042]	[13.203]	[4.205]
intangible	0.915***	-0.125	-78.710***	1.701
	[0.199]	[0.089]	[28.799]	[8.439]
firmage	-0.148**	-0.045	-27.386***	1.228
	[0.068]	[0.033]	[7.254]	[2.188]
salary	-0.002	-0.037***	-8.247***	-0.510
	[0.013]	[0.006]	[1.405]	[0.529]
_cons	-6.978***	0.754***	1914.613***	-11.970
	[0.335]	[0.164]	[44.105]	[12.732]
individuals	YES	YES	YES	YES
year	YES	YES	YES	YES
r2	0.719	0.870	0.826	0.107
N	22791.000	22791.000	22791.000	22791.000

4.6. Discussion of moderating mechanisms

The moderating effects of government attention and enterprise characteristics on the impact of the carbon peaking and carbon neutrality policies on manufacturing transformation and upgrading were assessed by adding interaction terms between the policy and government attention, as well as between the policy and whether the enterprise is a heavily polluting one, into the baseline regression model. Columns (1), (3), and (5) of Table 7 show that the interaction term between the carbon peaking and carbon neutrality policies and government attention has a significantly negative impact on corporate carbon dioxide emissions, a significantly positive impact on sustainable development, and an insignificant impact on sulfur dioxide emissions. This suggests that government attention exerts a positive moderating effect in the process by which the policy influences manufacturing transformation and upgrading. Specifically, an increase in government attention amplifies the negative impact of the policies on corporate carbon dioxide emissions and enhances its positive impact on sustainable development, thereby validating H4. Columns (2), (4), and (6) of Table 7 reveal that the moderating effects of enterprise characteristics are similar to those of government attention. The interaction term between the carbon peaking and carbon neutrality policies and whether the enterprise is heavily polluting shows a significantly negative impact on carbon dioxide emissions and a significantly positive impact on sustainable development, while the impact on sulfur dioxide emissions remains insignificant. This indicates that the nature of being a heavily polluting enterprise has a positive moderating effect on the policy's influence on manufacturing transformation and upgrading. When an enterprise is highly polluting, the negative impact of the policy on carbon dioxide emissions is amplified, as is its positive impact on sustainable development, thereby validating H5.

Firstly, the increase in government attention means a deeper emphasis on the dual carbon policy, which will prompt the government to introduce more specific and effective policy measures to promote the achievement of the dual carbon goals. These policy measures include fiscal subsidies, tax incentives, green finance support, etc., aimed at reducing the transformation costs of enterprises, encouraging them to adopt green and low-carbon technologies, and improving energy efficiency. The implementation of these policies will directly promote the green and low-carbon transformation of enterprises, laying a solid foundation for their sustainable development. Secondly, the increase in government attention also means strengthened supervision of the implementation of the dual carbon policy. The government will increase environmental supervision and carbon emission verification of enterprises to ensure that they reduce emissions in accordance with policy requirements. The establishment of such a supervision mechanism helps to create a fair competitive market environment, incentivize enterprises to increase investment in green and low-carbon technologies, and enhance their market competitiveness. At the same time, for enterprises that fail to achieve their emission reduction targets, the government will take corresponding punitive measures, which will also encourage enterprises to pay more attention to the implementation of the dual carbon policy and ensure that their production and operation activities meet the requirements of sustainable development. Finally, the increase in government attention will also promote the deep integration of dual carbon policies with other aspects of economic and social development. The government will actively promote the coordination and cooperation of dual carbon policies with industrial policies, energy policies, technological innovation policies, etc., forming a policy synergy to jointly promote the green, low-carbon and sustainable development of enterprises. This policy synergy not only helps to enhance the effectiveness of policy implementation, but also creates more development opportunities and market space for enterprises.

Table 7. Results of Moderating Effect Tests

	(1)	(2)	(3)	(4)	(5)	(6)
	co	co	so	so	sgrowth	sgrowth
gov	0.011		6.922		8.301***	
	[0.007]		[0.338]		[0.757]	
polution		0.536***		5.158		18.409***
		[0.023]		[4.560]		[1.644]
did_gov	-0.003*		-2.037***		0.353*	
	[0.002]		[-0.674]		[0.202]	
did_polution		-0.085***		-0.113		0.775***
		[0.004]		[0.759]		[0.277]
did	-0.041***	-0.028***	-6.588***	-5.366***	1.292*	1.428**
	[0.007]	[0.009]	[1.909]	[1.935]	[0.689]	[0.685]
size	0.009*	0.009*	-69.017***	-71.900***	1.720***	1.298**
	[0.005]	[0.005]	[1.864]	[1.900]	[0.524]	[0.521]
lev	0.089***	0.068***	-74.289***	-78.132***	2.276	1.459
	[0.018]	[0.021]	[6.853]	[6.963]	[1.814]	[1.815]
roa	-0.443***	-0.368***	-226.732***	-234.624***	9.116**	8.489**
	[0.037]	[0.039]	[12.961]	[13.199]	[4.165]	[4.173]
intangible	-0.156**	-0.130	-72.821**	-83.398***	4.828	-0.548
	[0.077]	[0.080]	[28.282]	[28.718]	[8.421]	[8.433]
firmage	-0.038	-0.036	-23.637***	-26.702***	1.781	1.073
	[0.025]	[0.029]	[7.087]	[7.248]	[2.186]	[2.193]
salary	-0.037***	-0.025***	-8.574***	-8.161***	-0.589	-0.305
	[0.005]	[0.005]	[1.383]	[1.407]	[0.528]	[0.528]
_cons	0.906***	0.625***	1561.902***	1942.680***	-104.907***	-32.237**
	[0.141]	[0.143]	[47.731]	[43.874]	[14.704]	[12.657]
individuals	YES	YES	YES	YES	YES	YES
year	YES	YES	YES	YES	YES	YES
r2	0.869	0.889	0.830	0.826	0.114	0.121
N	22791.000	22791.000	22791.000	22791.000	22791.000	22791.000

5. Conclusions and Policy Recommendations

Drawing on data from A-share listed enterprises from 2010 to 2023, this study provided a comprehensive evaluation of the impact of the carbon peaking and carbon neutrality policies on the transformation and upgrading of the manufacturing sector. By employing a series of econometric models, the study reveals both the overall effects of the policy and the mechanisms through which these effects occur. The key findings are as follows: (1) The baseline regression results show that the carbon peaking and carbon neutrality policies have a significantly negative effect on corporate emissions of carbon dioxide and sulfur dioxide, while exerting a significantly positive effect on sustainable development. This suggests that the policies play a critical role in driving the transformation and upgrading of the manufacturing sector. These findings remain robust even after a series of robustness tests, confirming their effectiveness. (2) Mediating and Moderating Effects: Mediating Mechanism: The carbon peaking and carbon neutrality policies facilitate manufacturing transformation by promoting green technologies and sustainable practices within enterprises, which are instrumental in reducing emissions and enhancing sustainable development. Moderating Mechanism: Government attention and the classification of enterprises as heavily polluting both serve as positive moderators in this process. Specifically, higher levels of government attention and the classification of an enterprise as heavily polluting strengthen the policy's negative impact on carbon dioxide emissions and its positive impact on sustainable development.

Based on the above conclusions, the following policy insights are drawn:

1. Given that the implementation of the carbon peaking and carbon neutrality policies promotes the transformation and upgrading of the manufacturing sector, it is imperative to continue advancing along this path set by the new era. Government should set clear carbon peak and carbon neutrality targets for the manufacturing industry based on scientific assessments, and develop corresponding emission reduction roadmaps. These goals should be both challenging and practical, guiding companies to gradually reduce carbon emissions while ensuring stable economic growth. The setting of emission reduction targets should take into account the actual situation of different industries and enterprises, ensuring the fairness and effectiveness of policies. Establish a sound legal and regulatory system related to carbon emissions,

and clarify the emission reduction responsibilities and obligations of enterprises. By legislative means, carbon emissions will be included in the cost considerations of enterprises, promoting their adoption of low-carbon technologies and production methods. At the same time, strengthen the regulatory capacity of environmental protection departments to ensure the effective implementation of laws and regulations. Illegal emissions should be severely punished in accordance with the law to form an effective deterrent. Government agencies should enhance policy guidance and foster environmental awareness among enterprises, reducing preferential policies that encourage traditional production methods. Instead, manufacturing enterprises should be gradually guided toward modern production methods characterized by sustainability, efficiency, and green practices. Furthermore, it is essential to accelerate the establishment and improvement of performance evaluation and supervision systems for the transformation and upgrading of manufacturing enterprises. Linking evaluation results to accountable entities will help ensure the healthy development of manufacturing firms along the transformation path.

2. The carbon peaking and carbon neutrality policies affect the transformation and upgrading of the manufacturing sector through green technological innovation, demonstrating that advancements in green technology have become an intrinsic driving force behind the policies' positive impact. Therefore, government departments should focus on cultivating and attracting technological talent, encouraging high-tech professionals to enter the manufacturing sector to drive its modernization. Government should increase investment in low-carbon technology research and development, and support enterprises, universities, and research institutions to carry out collaborative research. Promote the research and application of low-carbon technologies through the establishment of special funds and innovation platforms. At the same time, we will strengthen the introduction, digestion and absorption of international advanced low-carbon technologies, and enhance the low-carbon technology level of China's manufacturing industry. Based on regional resource endowment and industrial characteristics, optimize industrial layout and promote the formation of green and low-carbon industrial clusters. Encourage enterprises to gather in the park through planning guidance, policy support, and other means to achieve resource sharing and centralized pollution control. At the same time, strengthen environmental supervision of the park to ensure that it meets the requirements of low-carbon transformation. The government should set an example and promote green procurement policies. Prioritize low-carbon and environmentally friendly products and services in government procurement, and guide enterprises to transform towards green production. At the same time, encourage enterprises to engage in green procurement cooperation and form a green supply chain system. Additionally, manufacturing enterprises should intensify employee training programs to enhance their skills and management capacities, ensuring that workers can better adapt to market demands and societal development.
3. The positive impact of the carbon peaking and carbon neutrality policies on manufacturing transformation is strengthened by both increased government attention and the classification of enterprises as heavily polluting. As a result, government agencies should raise their focus on the policies and green development, offering fiscal support and policy incentives to encourage manufacturing enterprises to accelerate their transformation. Provide specialized technical transformation and industrial upgrading support for heavily polluting enterprises. By establishing special funds and providing technical consulting, we help enterprises introduce advanced low-carbon technologies and equipment, improve production efficiency and environmental protection levels. At the same time, encourage enterprises to conduct clean production audits and tap into the potential for energy conservation and emission reduction. On the other hand, for manufacturing enterprises with high pollution levels, stricter regulatory measures should be implemented to require them to accelerate the pace of low-carbon transformation. By conducting regular inspections and disclosing environmental information, we urge enterprises to rectify and upgrade, and reduce pollutant emissions. Enterprises that fail to rectify or refuse to comply should be severely punished according to law, up to the revocation of their business license. For high-pollution manufacturing enterprises, establishing green, low-carbon, and sustainable development demonstration enterprises could help summarize successful experiences and serve as a model, thereby more effectively driving the transformation and upgrading of the broader heavily polluting industry. In addition, through media promotion, community activities, and other means, we aim to raise public awareness and supervision of the low-carbon transformation of heavily polluting enterprises. Establish an environmental information disclosure system to enable the public to understand the emission situation and governance progress of enterprises. Encourage the public to report illegal emissions and create a good atmosphere of social governance.

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