Estimation of Carbon Emissions and Analysis of Influencing Factors in China's Furniture Industry

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ABSTRACT

Against the backdrop of China's "Dual Carbon" strategic goal, carbon emission issues in the furniture manufacturing industry—a pivotal light industry sector—remain understudied with systematic micro-level empirical evidence. Based on questionnaire survey data collected from 283 furniture manufacturing enterprises, this paper constructs a carbon emission measurement model tailored to the production characteristics of the industry, and empirically examines the impacts of enterprise scale, energy structure, technology level and other factors on carbon emission intensity per unit output value using a multiple linear regression model. The findings indicate that the average carbon emission intensity per unit output value of sample enterprises stands at 0.11 ton per 10,000 yuan. The industry presents distinct heterogeneous emission patterns: eastern regions outperform central and western regions, large-scale enterprises outperform micro and small enterprises, and enterprises with a higher share of clean energy demonstrate better emission efficiency. Specifically, wooden furniture enterprises register the highest emission intensity, while upholstered furniture enterprises record the lowest. Clean energy share, production process advancement and environmental protection facility configuration are identified as the three core determinants of carbon emission intensity, and all explanatory variables show a significant negative correlation with carbon emission intensity. These conclusions provide micro empirical support for formulating differentiated emission reduction policies and advancing energy structure optimization and process upgrading in the furniture manufacturing industry.

Keywords: Furniture manufacturing industry, Carbon emission intensity, Micro-enterprise data, Energy structure, Low-carbon transformation.

1 Introduction

Against the backdrop of continuous advancement of the "dual carbon control" policy, accurately identifying the carbon emission characteristics and influencing factors of sub-sectors in the manufacturing industry is of great significance for formulating differentiated low-carbon transformation paths. As an important livelihood industry and export pillar industry in China, the furniture manufacturing industry had a total operating revenue of over 700 billion yuan from industrial enterprises of designated scale in 2023, ranking first in the world in export volume. As an export-oriented sector, low-carbon transformation is also the core direction to enhance the green export competitiveness of the manufacturing industry (Jiang et al., 2024). As a typical discrete manufacturing industry, its production processes including cutting, spraying and assembly all involve energy consumption and carbon emission behaviors. Its characteristics of diversified energy structure, fragmented process links, and a high proportion of micro and small enterprises make its carbon emission driving mechanism essentially different from that of high energy-consuming industries such as steel and cement. Systematically revealing the carbon emission characteristics of the furniture manufacturing industry and accurately identifying key influencing factors have important practical significance for promoting the green transformation of the industry.

In terms of carbon emission measurement, life cycle assessment and carbon footprint accounting are the mainstream methods for research on furniture product carbon emissions. For wood, bamboo and rattan furniture products, existing studies have systematically sorted out the methodology system and research progress of carbon footprint assessment (Wan et al., 2024). For the broader field of wood and bamboo products, relevant studies have further improved the accounting framework and evaluation standards for forest product carbon footprints (Lao et al., 2024). From the supply chain perspective, relevant studies have identified key influencing factors for carbon emission reduction in the furniture supply chain through literature research, providing a reference for the whole-chain analysis of industry emission reduction (Long et al., 2024). Research on carbon footprint accounting of eco-designed furniture shows that carbon emissions of wood furniture are concentrated in the links of raw material acquisition and production and processing, and production-side energy consumption is the core source of carbon emissions in the whole product life cycle (Zhang et al., 2016).

At the macro research level of carbon emission influencing factors, existing literature has discussed from multiple dimensions such as industrial structure, energy structure, technological innovation and global value chain embedding (Wang & Guo, 2023). Some studies have also used the LMDI decomposition method to structurally decompose the embodied carbon emissions of manufacturing export trade (Wang & Fu, 2024). For the forest products industry, a study constructed an LMDI model incorporating technological progress, confirming that technological progress has a significant inhibitory effect on carbon emissions in the forest products industry and proposing targeted emission reduction paths (Tian et al., 2024). At the overall manufacturing level, studies have measured the regional differences and dynamic evolution characteristics of carbon emissions from industrial production energy consumption in China, finding significant differentiation in the regional carbon emission pattern (Wang et al., 2023). Case studies at the provincial level have further verified the key role of energy structure and technology level in carbon emission reduction of the manufacturing industry (Li & Sun, 2023). In addition, special research on the equipment manufacturing industry shows that process upgrading and structural adjustment are the core paths for achieving carbon peak in segmented manufacturing industries (Sun et al., 2023), providing a reference for emission reduction research on discrete manufacturing industries such as furniture. In recent years, the carbon emission reduction effect of digital transformation of the manufacturing industry in the context of the digital economy has also been widely verified. Relevant studies have carried out systematic analysis from multiple dimensions such as the overall emission reduction effect of digital transformation, the intermediary mechanism of green technology innovation, enterprise-level empirical tests and technology implementation paths (Bai et al., 2024; Liu & Chen, 2024; Chen & Zhang, 2024; Liu & Zhang, 2024), providing theoretical support and practical reference for the low-carbon digital transformation of segmented industries.

At the industry reality level, field surveys of wood furniture enterprises show that the overall level of pollution prevention and control in the current industry is relatively low, and there is an urgent demand for green production transformation (Zhang et al., 2023). Against this background, scholars have begun to explore the overall path of carbon control and emission reduction in the furniture industry, as well as the integrated development model of low-carbon transformation and intelligent manufacturing (Dai et al., 2024).

However, existing research still has shortcomings. First, most studies focus on high energy-consuming industries, and systematic research on carbon emissions in the furniture manufacturing industry is relatively scarce. Second, most research relies on macro statistical data and lacks micro enterprise-level data support, making it difficult to capture the differences in carbon emissions among enterprises of different scales and regions. Third, existing analytical frameworks are mostly designed for continuous high energy-consuming industries and have insufficient adaptability to the industry characteristics of the furniture manufacturing industry, such as fragmented processes and diversified energy structures. Based on this, this paper takes Chinese furniture manufacturing enterprises as the research object, conducts a questionnaire survey on 283 enterprises using stratified sampling, constructs a carbon emission measurement model adapted to the furniture industry based on the IPCC emission factor method, selects six indicators as explanatory variables, and uses a multiple linear regression model to empirically test the impact of each factor on carbon emission intensity per unit output value, so as to provide empirical support for precise emission reduction and low-carbon transformation of the furniture manufacturing industry.

2 Research Methodology

2.1 Data Source and Sample Characteristics

The data in this paper comes from a questionnaire survey of furniture manufacturing enterprises conducted from January to February 2026. The survey adopts the stratified random sampling method, takes the agglomeration degree of the furniture industry as the stratification basis, selects six major furniture manufacturing provinces including Guangdong, Zhejiang, Jiangsu, Shandong, Sichuan and Hebei as the main research areas, and conducts random sampling in each region according to the ratio of "large enterprises: medium-sized enterprises: micro and small enterprises = 2:3:5", taking into account the representativeness of enterprises of different scales. The survey adopts the mode of online survey as the main channel supplemented by offline field visits: online questionnaires are distributed via the online questionnaire system in cooperation with local furniture industry associations, while offline on-site visits and verifications are conducted for large leading enterprises. A total of 350 questionnaires were distributed and 312 were recovered. After eliminating questionnaires with incomplete filling, missing key indicators and obviously abnormal data, 286 valid questionnaires were obtained, with an effective recovery rate of 81.71%. After outlier elimination, 283 valid samples were finally retained.

The basic information of sample enterprises is shown in Table 1. In terms of scale distribution, there are 145 micro and small enterprises (50.70%), 89 medium-sized enterprises (31.12%), and 52 large enterprises (18.18%). The sample structure is consistent with the actual situation that micro and small enterprises account for the majority in the industry. In terms of regional distribution, Guangdong (26.92%) and Zhejiang (23.43%) account for more than 50% in total, and the distribution of the other four provinces is relatively balanced. In terms of ownership type, there are 247 private enterprises (86.36%), 12 state-owned enterprises (4.20%), and 27 foreign-funded enterprises (9.44%). In terms of main product categories, there are 121 wood furniture enterprises (42.31%), 73 metal furniture enterprises (25.52%), 63 upholstered furniture enterprises (22.03%), and 29 enterprises of other categories (10.14%).

Table 1: Distribution of basic information of sample enterprises

Dimension	Category	Number of samples	Proportion (%)
Enterprise scale	Large enterprises	52	18.18
	Medium-sized enterprises	89	31.12
	Micro and small enterprises	145	50.70
Region	Guangdong	77	26.92
	Zhejiang	67	23.43
	Jiangsu	45	15.73
	Shandong	38	13.29
	Sichuan	32	11.19
	Hebei	27	9.44
Ownership	Private enterprises	247	86.36
	State-owned enterprises	12	4.20

Dimension	Category	Number of samples	Proportion (%)
	Foreign-funded enterprises	27	9.44
Main product	Wood furniture	121	42.31
	Metal furniture	73	25.52
	Upholstered furniture	63	22.03
	Other categories	29	10.14
Total		286	100.00

Note: The table shows the initial valid sample size. After outlier elimination, 283 samples are finally included in the empirical analysis.

2.2 Variable Definition and Measurement

This paper takes carbon emission per unit output value (CPI) as the explained variable, calculated by the ratio of carbon emissions from the production link of enterprises to annual operating income, with the unit of tons per 10,000 yuan. A higher value indicates worse carbon emission efficiency (Zhang & Cui, 2022).

The explanatory variables select six core indicators from three dimensions: enterprise characteristics, production behavior, and input management, including enterprise scale, cleanliness of energy structure, R&D investment intensity, environmental protection facility configuration, advanced production technology, and environmental regulation implementation degree. The control variables include enterprise region and main product category, both set as dummy variables to control the heterogeneity of regional and product attributes.The specific definitions, symbols and measurement standards of all variables are listed in Table 2.

Table 2: Definition of research variables

Variable type	Variable name	Symbol	Definition and measurement	Quantitative standard
Explained variable	Carbon emission per unit output value	CPI	Ratio of carbon emissions from production to annual operating income	Continuous variable, unit: tons per 10,000 yuan
Explanatory variable	Enterprise scale	SC	Measured by number of registered employees	Large=3; Medium=2; Micro and small=1
	Cleanliness of energy structure	ES	Proportion of clean energy (electricity, natural gas) in total energy consumption	Continuous variable, range 0-100, unit: %
	R&D investment intensity	RD	Ratio of annual R&D expenditure to operating income	Continuous variable, range 0-10, unit: %
	Environmental protection facility configuration	EP	Perfection of carbon-related environmental protection facilities in production	No configuration=1; Basic=2; Complete=3; Full-process=4
	Advanced production technology	TC	Automation and refinement level of core process equipment	Traditional manual=1; Semi-automation=2; Full automation=3; Intelligent=4
	Environmental regulation implementation	ER	Policy implementation intensity and environmental management certification	Not implemented=1; Partially implemented=2; Fully implemented +

Variable type	Variable name	Symbol	Definition and measurement	Quantitative standard
				basic certification=3; Fully implemented + advanced certification=4
Control variable	Region	AREA	Provincial location of enterprise registration	Dummy variable, Hebei as reference group
	Main product category	TYPE	Core product category of the enterprise	Dummy variable, other categories as reference group

2.3 Carbon Emission Calculation Method

This paper uses the IPCC emission factor method to calculate carbon emissions from the production link of enterprises (Eggleston et al., 2006). This method calculates carbon emissions by accounting for the actual consumption of various energy types and multiplying by the corresponding emission factors, which is suitable for the measurement demand of diversified energy types in the furniture manufacturing industry. Research on carbon footprint assessment of wood and bamboo products also provides an important application reference for this measurement method (Lao et al., 2024). The calculation scope focuses on the production link, covering common energy types in furniture production such as electricity, natural gas, biomass energy and coal, excluding carbon emissions from non-production links such as office and daily life.

The calculation formula for total carbon emissions in the production link is:

$$E = \sum_{i=1}^{n} (AD_i \times EF_i) \qquad (1)$$

Where E is the total carbon emissions in the production link (tons of CO_2), AD_i is the annual consumption of the i-th energy type, and EF_i is the carbon emission factor of the corresponding energy. Fossil energy emission factors adopt the values recommended by IPCC, and power emission factors are adjusted based on the average value of China's regional power grids.

The calculation formula for carbon emission intensity per unit output value is:

$$CPI = \frac{E}{R} \qquad (2)$$

where CPI is the carbon emission intensity per unit output value of enterprises (tons per 10,000 yuan), and R is the annual operating income of enterprises (10,000 yuan).

2.4 Data Preprocessing

To ensure the reliability of the analysis results, systematic preprocessing is performed on the original data. First, the boxplot method is used to identify outliers of continuous variables. For extreme values exceeding 1.5 times the interquartile range, they are corrected or eliminated by checking with the original questionnaire, and a total of 3 abnormal samples are eliminated. Second, for continuous variables with a missing rate lower than 5%, the mean imputation method is used for filling, and for categorical variables, the mode imputation method is used. Finally, to eliminate the influence of dimensional differences on the regression model, Z-score standardization is performed on all continuous explanatory variables to convert them into standard data with a mean of 0 and a standard deviation of 1.

3 Theoretical Framework and Research Hypotheses

3.1 "Characteristic-Behavior-Performance" Analytical Framework

Carbon emission refers to the behavior of human beings emitting greenhouse gases into the atmosphere in production and life, among which carbon dioxide is the most representative greenhouse gas. Research on carbon footprint assessment of wood and bamboo products provides an important methodological basis for understanding the accounting logic of carbon emissions in the furniture manufacturing industry (Lao et al., 2024). Research on the synergy of pollution reduction and carbon reduction in Beijing's manufacturing industry shows that carbon emissions and air pollutants have the same source, and pollution reduction and carbon reduction have a synergistic effect (Yu et al., 2024). In industry research, carbon emission can be measured by both total emission index and carbon emission intensity per unit output value. The latter can more objectively reflect the carbon emission efficiency of different entities and is the core evaluation index in research on industry low-carbon development (Zhang & Cui, 2022). This study focuses on carbon emissions from the production link of the furniture manufacturing industry, and takes carbon emission intensity per unit output value as the core measurement index.

The furniture manufacturing industry is an important part of the light industry, using wood, metal, plastic, cloth art as main raw materials, and producing furniture products through cutting, coating, assembly and other processes. The industry has typical characteristics such as fragmented processes, diversified energy structure, obvious differentiation of enterprise scale and high proportion of micro and small enterprises, which make its carbon emission driving mechanism significantly different from that of continuous high energy-consuming industries such as steel and cement (Liu & Li, 2023). Green manufacturing is a manufacturing mode that integrates environmental protection concepts into the whole product life cycle, reducing resource consumption and pollution emissions through clean production technology and energy structure optimization (Li et al., 2023). Low-carbon transformation refers to the development mode transformation carried out by various industries in response to climate change, with the core of reducing carbon emission intensity in production and operation through technological innovation and energy substitution (Dai et al., 2024).

At the theoretical basis level, the low-carbon economy theory, with low energy consumption, low emission and low pollution as core characteristics, provides the overall goal orientation for carbon emission control of the manufacturing industry. The environmental regulation theory holds that reasonable environmental regulation policies can restrict enterprises' pollution emission behaviors and force enterprises to improve production processes and optimize energy structure (Liu & Li, 2023). Follow-up studies have further confirmed that environmental regulation can promote the green transformation of the manufacturing industry by improving green total factor productivity, and digital technology plays an important regulatory effect in it (Zhang & Han, 2023). The technological innovation theory emphasizes the key role of technological progress in improving resource utilization efficiency and reducing pollution emissions, and the coordinated development of scientific and technological innovation and industrial structure has an important impact on carbon emission reduction in the manufacturing industry (Liu et al., 2024). The above theories provide systematic theoretical support for the analytical framework of this paper from two levels: external constraints and endogenous motivation.

Based on the above concepts and theories, this paper constructs an analytical framework of "enterprise characteristics - production behavior - carbon emission performance" as the core logical basis of the research. Enterprise characteristics are basic variables, mainly including inherent attributes such as scale, region, and main product category, which affect enterprises' resource endowment and decision-making ability. Production behavior is an intermediary variable, covering active business behaviors such as energy structure selection, environmental protection facility investment, technology R&D investment, and low-carbon management measures. Carbon emission performance is the outcome variable, which measures the carbon emission efficiency of enterprises by carbon emission intensity per unit output value. Under this framework, enterprise characteristics ultimately affect carbon emission performance by influencing production behavior, providing a clear logical path for subsequent empirical analysis.

3.2 Research Hypotheses

Based on the above theoretical framework and the actual situation of the furniture manufacturing industry, this paper proposes the following research hypotheses:

H1: Enterprise scale is negatively correlated with carbon emission intensity. Large furniture enterprises have sufficient funds and technical reserves, and are more capable of carrying out energy-saving transformation and low-carbon management, while micro and small enterprises have limited emission reduction capacity due to resource constraints.

H2: The cleanliness of energy structure is negatively correlated with carbon emission intensity. The carbon emission factors of clean energy such as electricity and natural gas are lower than those of coal and biomass energy, and increasing the proportion of clean energy can directly reduce the total carbon emissions in the production link.

H3: R&D investment intensity is negatively correlated with carbon emission intensity. The increase of R&D investment helps promote the application of low-carbon technologies and energy-saving processes, reducing emission intensity from the technical level.

H4: Environmental protection facility configuration is negatively correlated with carbon emission intensity. Perfect environmental protection facilities can effectively deal with carbon emissions and pollutants in the production process, achieving end-of-pipe emission reduction.

H5: Advanced production technology is negatively correlated with carbon emission intensity. Automated and intelligent advanced processes can reduce energy waste and material loss in the production process and improve energy utilization efficiency.

H6: The implementation degree of environmental regulation is negatively correlated with carbon emission intensity. The higher the implementation intensity of carbon emission reduction policies and the more perfect the environmental management certification, the more active the emission reduction behaviors of enterprises.

4 Results and Discussion

4.1 Carbon Emission Characteristics of the Furniture Manufacturing Industry

4.1.1 Overall Carbon Emission Intensity

Based on the measurement model constructed above, the carbon emissions from the production link of 283 sample enterprises are calculated. The results show that the average carbon emission intensity per unit output value of China's furniture manufacturing industry is 0.11 tons per 10,000 yuan, and the overall data shows a right-skewed distribution. Most enterprises are concentrated near the average value, while a few enterprises are far higher than the industry average, most of which are micro and small enterprises relying on traditional production processes and extensive energy structure. In terms of energy contribution, carbon emissions from electricity consumption account for the largest proportion, followed by natural gas and biomass energy, and coal use accounts for a very low proportion. This is consistent with the conclusion in the carbon footprint accounting research of eco-designed furniture that energy consumption is the main emission source at the production end (Zhang et al., 2016), indicating that energy consumption in China's furniture manufacturing industry has gradually developed towards clean energy, but the problem of uneven emission efficiency within the industry is still prominent.

4.1.2 Carbon Emission Comparison by Product Category

After eliminating 3 abnormal data samples (all belonging to other categories), the valid samples are divided into four groups according to the main product category: wood furniture, metal furniture, upholstered furniture and other categories. The measurement results show obvious layered characteristics, and the emission intensity of wood furniture enterprises is significantly higher than that of other categories, which is consistent with the industry characteristic conclusion in the research on life-cycle carbon emission reduction design of wood furniture (Wang et al., 2023).

Wood furniture enterprises have the highest carbon emission intensity, with an average of 0.18 tons per 10,000 yuan. Their processes such as wood drying, cutting and grinding account for a large proportion of energy consumption, and 35% of enterprises still use biomass energy. Metal furniture enterprises rank second, with an average of 0.12 tons per 10,000 yuan, and almost all carbon emissions come from electricity consumption. Upholstered furniture enterprises have the lowest average of 0.07 tons per 10,000 yuan. Their production is mainly based on cloth processing and sponge filling, without high energy consumption processes, and the output value of a single product is relatively high. Enterprises of other furniture categories have an average of 0.10 tons per 10,000 yuan.

Table 3: Comparison of carbon emission intensity of furniture enterprises by product category

Main category	Number of samples	Average carbon emission intensity (tons/10,000 yuan)	Average proportion of clean energy (%)	Main emission source
Wood furniture	121	0.18	61.2	Biomass energy, electricity
Metal furniture	73	0.12	74.8	Electricity (welding, forming)
Upholstered furniture	63	0.07	82.3	Electricity (lighting, sewing)
Other categories	26	0.10	70.5	Large differences

Note: After eliminating 3 abnormal data samples, there are 26 valid samples of other categories.

4.1.3 Regional Differences

The carbon emission intensity of sample enterprises presents a regional differentiation characteristic of "low in the east and high in the west". The average emission intensity of Guangdong Province is 0.09 tons per 10,000 yuan, Zhejiang Province is 0.08 tons per 10,000 yuan, and Jiangsu Province is 0.10 tons per 10,000 yuan, all lower than the industry average. Among the central and western provinces, Sichuan Province is 0.15 tons per 10,000 yuan, Hebei Province is 0.14 tons per 10,000 yuan, and Shandong Province is 0.12 tons per 10,000 yuan. In terms of the proportion of clean energy use, the average proportion of clean energy in sample enterprises in Guangdong and Zhejiang reaches more than 85%, while that in Sichuan and Hebei is only about 60%.

National regional scale studies also show that there are significant differences in carbon emission patterns in different regions, and there is an obvious industrial carbon transfer phenomenon at the provincial level. The difference in energy structure is the core reason for the differentiation of regional emission intensity (Wang et al., 2023; Chen et al., 2023). The regional differentiation of the furniture industry also conforms to this rule. The eastern coastal areas have high industrial agglomeration and perfect clean energy infrastructure, so the overall emission efficiency is better, as illustrated in Figure 1.

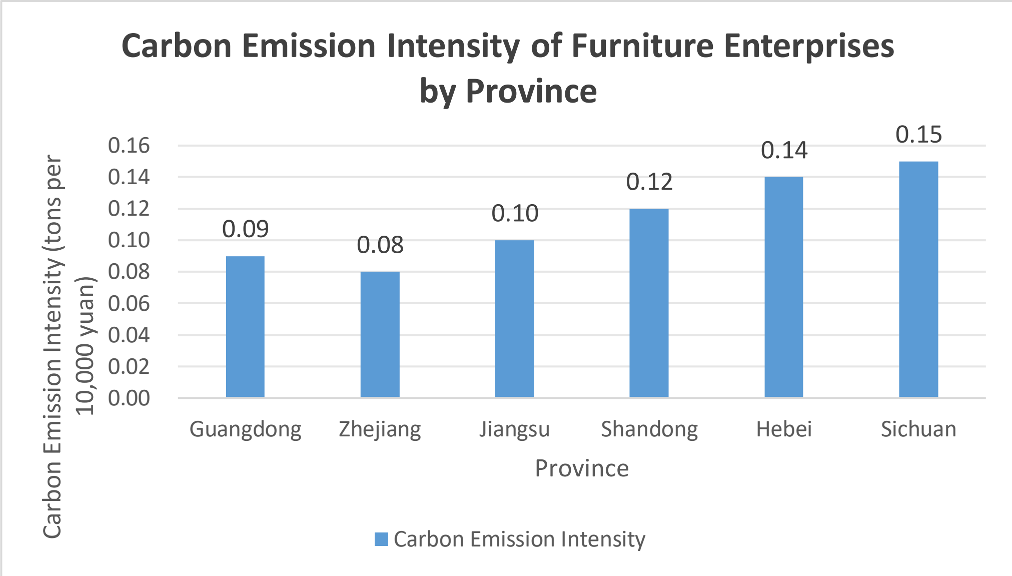

Figure 1: Comparison of carbon emission intensity of furniture enterprises by province

4.1.4 Scale Differences

The carbon emission intensity of enterprises of different scales shows significant gradient differences, which is negatively correlated with enterprise scale. Environmental target constraints have an important impact on the pollution discharge behavior of manufacturing enterprises, and enterprises of different scales face obvious differences in environmental constraints and emission reduction capabilities (Huang et al., 2023), so carbon emission performance also presents gradient differentiation.

Large enterprises have an average carbon emission intensity of 0.06 tons per 10,000 yuan, with clean energy accounting for 92%, and more than 90% of enterprises are equipped with full-process environmental protection facilities. Medium-sized enterprises have an average of 0.10 tons per 10,000 yuan, 65% of enterprises have a clean energy proportion between 70% and 80%, and only 30% are equipped with complete environmental protection facilities. Micro and small enterprises have an average of 0.15 tons per 10,000 yuan, with clean energy accounting for only 58%, and only 12% equipped with basic environmental protection facilities. On the whole, the larger the scale, the more obvious the advantages in capital, technology and energy management, and the higher the carbon emission efficiency. The specific comparison is shown in Figure 2.

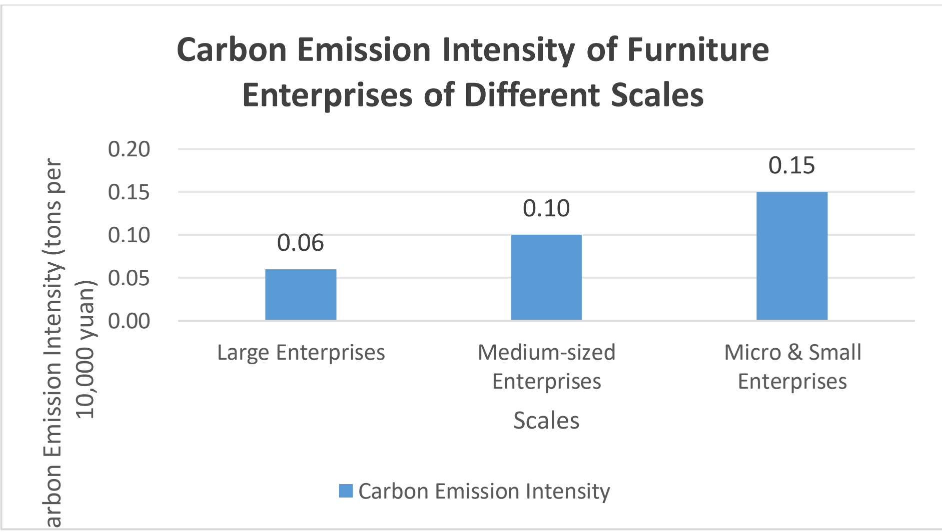

Figure 2: Comparison of carbon emission intensity among furniture enterprises of different scales

4.1.5 Energy Structure Differences

The sample enterprises are divided into three groups according to the proportion of clean energy, with significant emission differences. Research on the sustainable development system of the furniture industry also shows that energy structure optimization is the core path to reduce industry carbon emissions, and clean energy substitution has the most direct contribution to emission reduction (Li & Zhao, 2023).

Enterprises with clean energy accounting for more than 80% (96 enterprises) have an average carbon emission intensity of only 0.05 tons per 10,000 yuan, almost all using electricity and natural gas. Enterprises with clean energy accounting for 50%-80% (128 enterprises) have an average of 0.11 tons per 10,000 yuan, which is consistent with the overall industry level. Enterprises with clean energy accounting for less than 50% (59 enterprises) have an average as high as 0.20 tons per 10,000 yuan, all of which are micro and small enterprises mainly producing wood furniture. Biomass energy accounts for more than 50% of energy consumption, and some enterprises still use a small amount of coal.The gradient difference is presented in Figure 3.

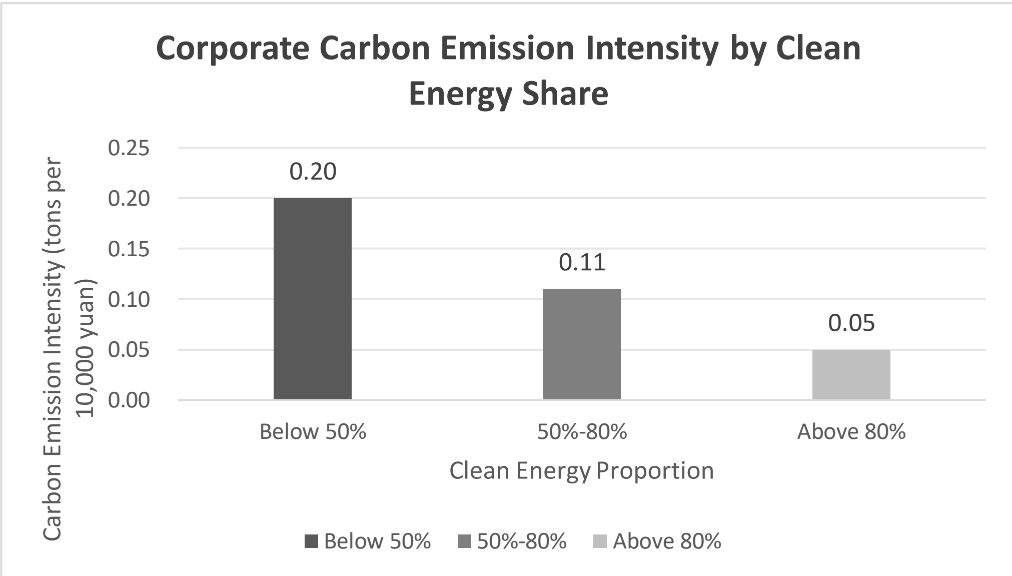

Figure 3: Comparison of carbon emission intensity across clean energy share groups

4.2 Empirical Analysis of Influencing Factors

4.2.1 Descriptive Statistics and Correlation Analysis

The descriptive statistics of each variable are shown in Table 4. The average value of the explained variable CPI is 0.11 tons per 10,000 yuan, with a standard deviation of 0.06, and the maximum and minimum values are 0.23 and 0.03 respectively, indicating that there are certain differences in carbon emission intensity among sample enterprises. The average ES is 68.25%, with a standard deviation of 18.32, indicating large differences in energy structure among enterprises. The average RD is 1.28%, with a maximum of 5.63% and a minimum of 0, indicating that most enterprises have low R&D investment. The average values of SC, EP, TC and ER are all around 2, indicating that the samples are mainly small, medium and micro enterprises, and environmental protection facilities and production processes are at a medium level.

Table 4: Descriptive statistics of core variables

Variable	Sample size	Mean	Std. Dev.	Minimum	Maximum
CPI	283	0.11	0.06	0.03	0.23
SC	283	1.68	0.75	1.00	3.00

Variable	Sample size	Mean	Std. Dev.	Minimum	Maximum
ES	283	68.25	18.32	25.36	98.74
RD	283	1.28	1.05	0.00	5.63
EP	283	2.15	0.89	1.00	4.00
TC	283	2.02	0.92	1.00	4.00
ER	283	2.23	0.86	1.00	4.00

Pearson correlation analysis shows that CPI is negatively correlated with all explanatory variables, and the absolute values of correlation coefficients with ES (-0.623) and TC (-0.587) are relatively large (P<0.01). The absolute values of correlation coefficients among all explanatory variables are less than 0.7, and all VIF values are less than 2, indicating that there is no serious multicollinearity problem.

Table 5: Pearson correlation analysis

Variable	CPI	SC	ES	RD	EP	TC	ER
CPI	1						
SC	-0.412***	1					
ES	-0.623***	0.589***	1				
RD	-0.357***	0.426***	0.513***	1			
EP	-0.501***	0.652***	0.598***	0.487***	1		
TC	-0.587***	0.615***	0.632***	0.502***	0.605***	1	
ER	-0.458***	0.527***	0.496***	0.463***	0.554***	0.518***	1

4.2.2 Benchmark Regression Results

To verify the net impact of each factor on carbon emission intensity, a multiple linear regression model is constructed with carbon emission per unit output value (CPI) as the explained variable, six core indicators as explanatory variables, and region and product category as control variables:

$$\mathrm{CPI} = \alpha_0 + \alpha_1\mathrm{SC} + \alpha_2\mathrm{ES} + \alpha_3\mathrm{RD} + \alpha_4\mathrm{EP} + \alpha_5\mathrm{TC} + \alpha_6\mathrm{ER} + \alpha_7\mathrm{AREA} + \alpha_8\mathrm{TYPE} + \varepsilon$$

Where α_0 is the intercept term, α_1 to α_8 are regression coefficients, and ε is the random error term. All continuous variables (ES, RD) have been standardized by Z-score, and the regression coefficients reflect the impact of a one-standard-deviation change in the independent variable on the dependent variable. The stepwise regression method is used for parameter estimation, and the regression results are shown in Table 4.

The adjusted R^2 of the model is 0.765, and the F value is 89.326 (P<0.01), indicating a good goodness of fit. All core explanatory variables have negative regression coefficients and P<0.01, and all six hypotheses are verified. The degree of influence from large to small is: cleanliness of energy structure (-0.325), advanced production technology (-0.268), environmental protection facility configuration (-0.215), enterprise scale (-0.186), environmental regulation implementation degree (-0.157), and R&D investment intensity (-0.123). The VIF values of all explanatory variables range from 1.598 to 2.015, far below the critical value of 10, indicating that the model has no serious multicollinearity problem.

Table 6: Multiple linear regression results

Variable	Coefficient	Std. Error	t-value	p-value	VIF
Intercept	0.108***	0.012	8.96	0.000	-
SC	-0.186***	0.035	-5.31	0.000	1.89
ES	-0.325***	0.042	-7.74	0.000	1.96
RD	-0.123***	0.028	-4.39	0.000	1.79
EP	-0.215***	0.039	-5.51	0.000	1.92
TC	-0.268***	0.045	-5.96	0.000	2.02
ER	-0.157***	0.032	-4.91	0.000	1.82
AREA	-0.089*	0.047	-1.89	0.059	1.65
TYPE	-0.076*	0.041	-1.85	0.065	1.60
Adj. R^2	0.765				
F-value	89.33***		0.000		
N	283				

4.2.3 Robustness Test and Model Diagnosis

To ensure the reliability and stability of the regression results, verification is carried out from two dimensions: robustness test and model diagnosis.

Robustness test: Two methods are used for cross-validation. First, replace the explained variable: replace the original explained variable "carbon emission per unit output value" with "carbon emission per unit output" and re-run the regression. Second, eliminate extreme values: eliminate the upper and lower 1% extreme samples of the explained variable (6 in total) and re-run the regression on the remaining 277 samples. The results of both tests show that the signs of the regression coefficients of each core explanatory variable remain unchanged, the significance is consistent with the original model, the ranking of influence degree remains stable, and only the absolute value of the coefficient fluctuates slightly. The adjusted R^2 is 0.742 after replacing the explained variable and 0.758 after eliminating extreme values, both close to 0.765 of the benchmark model, indicating that the results of the original model are robust.

Model diagnosis: For residual normality test, the K-S one-sample test statistic is 0.068, with a P-value of 0.236, which is greater than the significance level of 0.05. The null hypothesis that the residuals follow a normal distribution cannot be rejected, indicating that the model residuals meet the normality assumption. For heteroscedasticity test, the White test statistic is 18.342, with a P-value of 0.189, which is greater than 0.05, accepting the null hypothesis of homoscedasticity, indicating that the model has no heteroscedasticity. Based on the above test results, the model setting is reasonable and the regression coefficient estimators are effective.

4.3 Discussion of Results

The benchmark regression results verify the applicability of the "characteristic-behavior-performance" analytical framework in the research on carbon emissions of the furniture manufacturing industry: enterprise characteristics and management behaviors jointly affect carbon emission performance, and the influence intensity of behavioral factors is significantly higher than that of characteristic factors. According to the action mechanism and influence intensity, the six core factors can be divided into three echelons.

The first echelon is the cleanliness of energy structure, which is the most core factor affecting carbon emission intensity. Its emission reduction effect is the most direct: carbon emissions from the production link of the furniture manufacturing industry are highly dependent on energy consumption. The carbon emission factors of clean energy such as electricity and natural gas are significantly lower than those of coal and biomass energy, and energy substitution can directly reduce the carbon emission level per unit energy consumption from the source. This conclusion is consistent with the consensus in forest products industry emission reduction research that "energy structure optimization is the core starting point for emission reduction" (Tian et al., 2024; Li & Zhao, 2023). At the same time, it can also explain the core cause of emission differences in regional and scale dimensions: the emission advantages of eastern regions and large enterprises essentially stem from a higher penetration rate of clean energy.

The second echelon includes advanced production technology and environmental protection facility configuration, which reduce carbon emissions from two paths: production process optimization and end-of-pipe treatment respectively. Research on low-carbon manufacturing technology paths points out that the automation and intelligent upgrading of production processes can accurately control the energy consumption intensity of high energy-consuming processes, which is the core technical means for emission reduction at the production end (Li et al., 2023). Research on wood furniture carbon emission reduction design also confirms that process optimization and supporting environmental protection facilities can effectively reduce carbon emission intensity in the production link (Wang et al., 2023). Together, they constitute the process support for emission reduction in the production link and are the main focus for emission reduction transformation of small and medium-sized furniture enterprises.

The third echelon includes enterprise scale, environmental regulation implementation degree and R&D investment intensity, which affect carbon emissions through indirect paths, with relatively weak influence intensity. The emission reduction effect of enterprise scale stems from scale effect and resource endowment advantages, and larger enterprises have stronger emission reduction capacity under environmental constraints (Huang et al., 2023). The influence coefficient of environmental regulation implementation degree is relatively low, which may be related to the fact that current environmental regulation in the furniture industry is still dominated by pollutant treatment and special carbon emission constraint policies are still in the initial stage. This also echoes the research conclusion that the green transformation effect of environmental regulation has industry heterogeneity (Zhang & Han, 2023). The elasticity of R&D investment intensity is the smallest. On the one hand, it is related to the low overall R&D investment level of sample enterprises. On the other hand, it also reflects that the current R&D focus of enterprises is mostly concentrated on product design and capacity expansion, with insufficient special investment in low-carbon process technology, and the carbon emission reduction effect of scientific and technological innovation has not been fully released (Liu et al., 2024).

On the whole, the carbon emission driving mechanism of the furniture manufacturing industry presents the characteristics of "energy structure leading, process and facility supporting, scale and regulation supplementing". This means that industry emission reduction cannot only rely on policy pressure. Instead, it should take clean energy structure as the primary path, simultaneously promote production process upgrading and popularization of environmental protection facilities, and formulate differentiated support policies for micro and small enterprises and central and western regions, so as to achieve the overall improvement of emission reduction efficiency.

5 Conclusions

Based on micro data from 283 furniture manufacturing enterprises in China, this paper uses the IPCC emission factor method to measure carbon emissions from the production link, and tests the influencing factors of carbon emission intensity with a multiple linear regression model. The main conclusions are as follows.

First, the average carbon emission intensity per unit output value of China's furniture manufacturing industry is 0.11 tons per 10,000 yuan, with significant internal differences. The emission intensity presents the characteristics of being low in the east and high in the west, better in large enterprises than in micro and small enterprises, higher in wood furniture than in upholstered furniture, and significantly better in enterprises with a high proportion of clean energy than in those with a low proportion, indicating that energy structure and production technology level are the key factors determining emission efficiency.

Second, all six factors are significantly negatively correlated with carbon emission intensity. The degree of influence ranks as follows: cleanliness of energy structure, advanced production technology, environmental protection facility configuration, enterprise scale, environmental regulation implementation degree, and R&D investment intensity. Among them, the clean energy structure has the most prominent emission reduction effect. The results verify the core logic of the "characteristic-behavior-performance" analytical framework: enterprise characteristics ultimately determine carbon emission performance by influencing production behavior, and behavioral factors are decisive variables.

Third, micro and small enterprises and central and western provinces are the key and difficult points of emission reduction. Micro and small enterprises are at a disadvantage in capital, technology and management, while central and western provinces have insufficient popularization of clean energy infrastructure and advanced production technology, which provides empirical basis for implementing differentiated emission reduction policies.

Due to data availability constraints, this study only covers six major furniture-producing provinces and does not involve a longer time series for dynamic tracking. Future research can expand the sample scope and conduct longitudinal tracking to explore the long-term evolution mechanism of industry carbon emissions.

6 Declarations

6.1 Study Limitations

This study is limited by sample coverage and cross-sectional data. The sample only covers six major furniture-producing provinces in China, and the representativeness for remote regions with underdeveloped furniture industry is insufficient. Meanwhile, the cross-sectional data cannot capture the dynamic evolution trend of enterprise carbon emissions over time. In addition, the measurement of carbon emissions only covers the production link and does not include the full life cycle of raw material acquisition and product use, which may lead to a certain deviation in the total emission estimation.

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6.4 Competing Interests

The authors declare no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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