Carbon Dioxide Emission Evaluations in the Chinese Furniture Manufacturing Industry Using the IPCC Tier-2 Methodology

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Abstract

Estimating industrial carbon dioxide emissions at the national scale is crucial for China's carbon peak and carbon neutralization targets, as well as the low-carbon development of the Chinese furniture manufacturing industry. For this purpose, in this study the Intergovernmental Panel on Climate Change Tier-2 methodology was used to evaluate the carbon dioxide emissions of the Chinese furniture manufacturing industry at the national scale. The results show that carbon dioxide emissions increased from 219.50 × 10,000 tons of CO_2 equivalent in 2000 to 850.68 × 10,000 tons of CO_2 equivalent in 2019. Moreover, carbon dioxide emission intensity decreased from 9.50 tons of CO_2 per million dollars to 1.73 tons of CO_2 per million dollars in this period. Moreover, electricity and raw coal were observed to have a significant influence on carbon dioxide emissions, followed by diesel oil, gasoline, heat energy, and natural gas. The results reveal that the Chinese furniture manufacturing industry has generally realized low-carbon development over the past two decades. This work proposes several suggestions to reduce carbon dioxide emissions from the Chinese furniture manufacturing industry, including promoting the use of clean electricity, the installation of photovoltaic cells, industrial transformation and upgrading, the optimization of transport modes for product delivery and material supply, and the employment of low-carbon raw materials.

Global warming, caused by carbon dioxide emissions, is a serious problem and has triggered great motivation for reducing carbon emissions (Chen et al. 2020). As the biggest developing country and the largest emitter of carbon dioxide (Lin and Sun 2010), China has set a target to reach a carbon dioxide emission peak by 2030 and achieve carbon neutralization by 2060 (Zhao et al. 2022). The industrial sector in China, which is the major contributor to its carbon dioxide emissions, plays an important role in achieving the carbon peak and carbon neutralization goals (Chen 2011). Hence, estimating the carbon dioxide emission of different industrial sectors in China is important not only for carbon peak and carbon neutralization targets, but also to industrial high-quality development.

The furniture manufacturing industry is one of the most important industrial sectors of the Chinese economy and produces a variety of consumer goods (Xiong et al. 2017). According to the National Bureau of Statistics of China (NBSC 2021 [2001 to 2021]), the Chinese furniture manufacturing sector is divided into wood furniture manufacturing, bamboo and rattan furniture manufacturing, metal furniture manufacturing, plastic furniture manufacturing, and others. Following the classification of Chinese Statistics (NBSC 2021 [2001 to 2021]), in 2020, there are 6,531 above-scale furniture manufacturing enterprises that are responsible for revenues in excess of 104.63 billion dollars (706.98 billion yuan). Moreover, these Chinese furniture manufacturing enterprises generate around 1.12 million jobs in 2020 (NBSC 2021). It is reported that the imports and exports of the Chinese furniture manufacturing industry reach approx-

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imately 59.76 billion dollars (403.76 billion yuan) and 2.31 billion dollars (15.59 billion yuan; NBSC 2021 [2001 to 2021]), respectively. The furniture manufacturing sector plays a crucial role in China, so there is an urgent need to evaluate its carbon dioxide emissions at the national scale.

In the furniture manufacturing sector, several environmental life-cycle assessment (LCA) case studies, including those for carbon dioxide emissions, have been performed for different kinds of furniture products. For example, Spitzley et al. (2006) studied the environmental impact of siento chairs, airtouch tables, and garland desks in the USA. In Norway, Askham et al. (2012) conducted an analysis of wood coatings, office chairs and conference or visitor chairs. González-García et al. (2011, 2012) analyzed the environmental profile of indoor and outdoor furniture, and wooden childhood furniture in Spain. Iritani et al. (2015) provided an LCA case study of wooden wardrobes produced in Brazil. Medeiros et al. (2017) diagnosed the environmental performance of an office cabinet in Brazil. However, studies focusing on the carbon dioxide emissions of furniture production are limited. Linkosalmi et al. (2016) assessed the greenhouse gas emissions for the production of eight different types of wood-based furniture in Finland. In summary, these micro-scale LCA studies provide support indicators that help identify the environmental hotspots and determine the opportunities to improve the environmental performances of furniture products. However, the carbon dioxide emissions of the furniture manufacturing sector at the macro level remain to be understood. There are currently no published national-scale studies on the carbon dioxide emissions of the furniture manufacturing sector in China.

The Intergovernmental Panel on Climate Change (IPCC) Tier-2 methodology is an accurate and powerful technique that is widely used for the assessment of carbon dioxide emissions in many other fields (Peter et al. 2016). For example, the IPCC Tier-2 methodology has been used to quantify CO_2 emissions from cropland in Norway (Borgen et al. 2012) and to predict soil CO_2 emissions and sinks (Silva-Parra et al. 2020). However, there is a lack of research on the estimation of carbon dioxide emissions of the furniture manufacturing sector using the IPCC Tier-2 methodology.

In this paper, the IPCC Tier-2 methodology was employed to estimate the carbon dioxide emissions of the Chinese furniture manufacturing industry at the national scale over the past two decades and to propose the path to further reductions in carbon emissions.

Research objective and methods

In order to obtain the carbon dioxide emissions of the whole industry at the national scale, the research objective is China's furniture manufacturing sector, including wood, bamboo and rattan, metal, and plastic furniture manufacturing. The carbon dioxide emissions of these subdivision fields cannot be calculated on account of the unavailability of statistical data. In addition, this study does not involve specific furniture products and production technology.

Calculation methods of carbon dioxide emissions

The carbon dioxide emissions of the Chinese furniture manufacturing industry are mainly attributed to energy sources including raw coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas, electricity, and heat energy used in production process. Hence, we adopted the IPCC Tier-2 methodology (IPCC 2006) to calculate the carbon dioxide emissions. The calculation formula is as follows:

$$\mathrm{CDE} = \sum_{i=1}^{n} (\mathrm{AD}_i \times \mathrm{EF}_i) \tag{1}$$

where CDE denotes carbon dioxide emissions; and AD_i and EF_i are the activity data and emission factor of energy source *i,* respectively.

$$\mathrm{AD}_i = \mathrm{NCV}_i \times \mathrm{FC}_i \tag{2}$$

where NCV_i and FC_i are the net calorific value and consumption of energy source *i,* respectively.

$$\mathrm{EF}_i = \mathrm{CC}_i \times \mathrm{OF}_i \times \frac{44}{12} \tag{3}$$

where CC_i is the carbon content per unit of calorific value of energy source *i*; OF_i, is the carbon oxidation rate of energy source *i*; and 44/12 is the ratio of the relative molecular mass of the carbon dioxide to carbon.

In order to examine the carbon dioxide emissions per unit of the output value, we also calculate the carbon dioxide emission intensity (Pretis and Roser 2017):

$$\mathrm{CEI} = \mathrm{CDE} \;/\; \mathrm{OV} \tag{4}$$

where CEI is the carbon dioxide emission intensity; CDE is the carbon dioxide emissions; and OV is the output value.

Data sources

In order to guarantee the reliability of results, high-quality data were obtained from the official reports released by the IPCC and China's authorities. The energy consumption data of the Chinese furniture manufacturing industry were obtained from the China Energy Statistical Yearbook (NBSC 2001 to 2020). The output values of the Chinese furniture manufacturing industry were taken from the China Statistical Yearbook (NBSC 2001 to 2020). The reference data used to calculate the emission factors of different energy source types producing energy per unit are listed in Table 1.

The net calorific values were collected from the China Energy Statistical Yearbook (NBSC 2013), the China National Standard GB/T 2589-2020 general rules for the calculation of comprehensive energy consumption published by the State Administration for Market Regulation of China and Standardization Administration of China (Standardization Administration of China [SAC] 2020), and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006), respectively. The carbon content per unit of calorific value and carbon oxidation rate were sourced from the Guidelines for Provincial Greenhouse Gas Inventories compiled by the National Development and Reform Commission of China (2011). The emission factor of heat energy was based on the China National Standard GB/T 32151.5-2015 Requirements of Greenhouse Gas Emissions Accounting and Reporting—Part 5: Iron and Steel Production Enterprise released by the General Administration of Quality Supervision Inspection and Quarantine of China and SAC (SAC 2015). The emission factor of electricity was taken from the Carbon Dioxide Emission Factor for the Chinese Regional Power Grid

Table 1.—Reference data used to calculate the emission factor of different kinds of energy sources producing energy per unit. [a,b]

Energy sources	NCV (GJ/t or GJ/10^4 Nm^3)	CC (t C/TJ)	OF	EF (t CO_2/GJ)
Coal				
Raw coal	20.908	26.37	0.94	0.0908886
Coke[c]	28.435	29.50	0.93	0.100595
Petroleum products				
Gasoline	43.070	18.90	0.98	0.067914
Diesel oil	42.652	20.20	0.98	0.072585333
Fuel oil	41.816	21.10	0.98	0.075819333
Liquefied petroleum gas[d]	50.179	17.20	0.98	0.061805333
Natural gas	389.310	15.30	0.99	0.055539
Liquefied natural gas	51.489	17.20	0.98	0.061805333
Electricity (kg CO_2/ kW·h)				0.6808
Heat energy[e] (t CO_2/GJ)				0.11

[a] Data were collected from the official reports released by Intergovernmental Panel on Climate Change and China's authorities.
[b] NCV = net calorific value; CC = carbon content; OF = carbon oxidation rate; EF = emission factor.
[c] Coke is a solid, black substance that is produced from coal and is burned as a fuel.
[d] Liquefied petroleum gas is a gas product of petroleum refining primarily consisting of propane, some propylene, butane, and other light hydrocarbons.
[e] Heat energy is a form of energy that is transferred by steam, hot water, and so forth.

published by the National Center for Climate Change Strategy and International Cooperation of China (2012).

Results

Output value of the Chinese furniture manufacturing industry

Figure 1 presents the output values of the Chinese furniture manufacturing industry from 2000 to 2019 (NBSC 2001 to 2020). Driven by the rapid development of the domestic economy and real estate industry (Xiong et al. 2017), the Chinese furniture manufacturing industry has achieved significant progress during the past two decades. The output value of the Chinese furniture manufacturing industry grew from 5.11 billion dollars (34.46 billion yuan) in 2000 to 108.94 billion dollars (734.6 billion yuan) in 2019, with the average annual growth rate at 18.60 percent. Note that the output value of the Chinese furniture manufacturing industry exhibited an obvious decline in 2018 as a result of the slowdown in China's real estate market. Moreover, the number of above-scale furniture manufacturing enterprises increased by approximately 4.3 times, from 1,498 in 2000 to 6,472 in 2019.

Energy consumption of the Chinese furniture manufacturing industry

Figure 2 depicts the energy consumption data of the Chinese furniture manufacturing industry from 2000 to 2019 (NBSC 2001 to 2020). It is well-known that energy sources are the foundation of industrial activity. With the rapid development of the Chinese furniture industry, the energy consumption increased rapidly from 69.75 × 10,000 tons of standard coal equivalents in 2000 to 206.9 × 10,000 tons of standard coal equivalents in 2015. Since 2016, the energy consumption of the Chinese furniture industry displayed a downward trend, from 190.14 × 10,000 tons of standard coal equivalents to 180.87 × 10,000 tons of standard coal equivalents. This reveals the gradual transformation of the energy consumption structure of the Chinese furniture manufacturing industry from raw coal, gasoline, diesel oil,

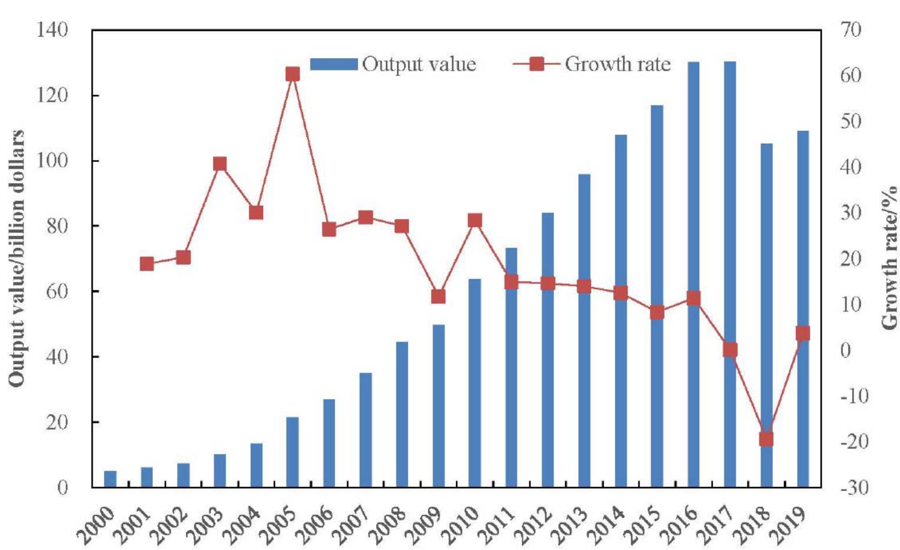

Figure 1.—Output value of Chinese furniture manufacturing industry in the period from 2000 to 2019.

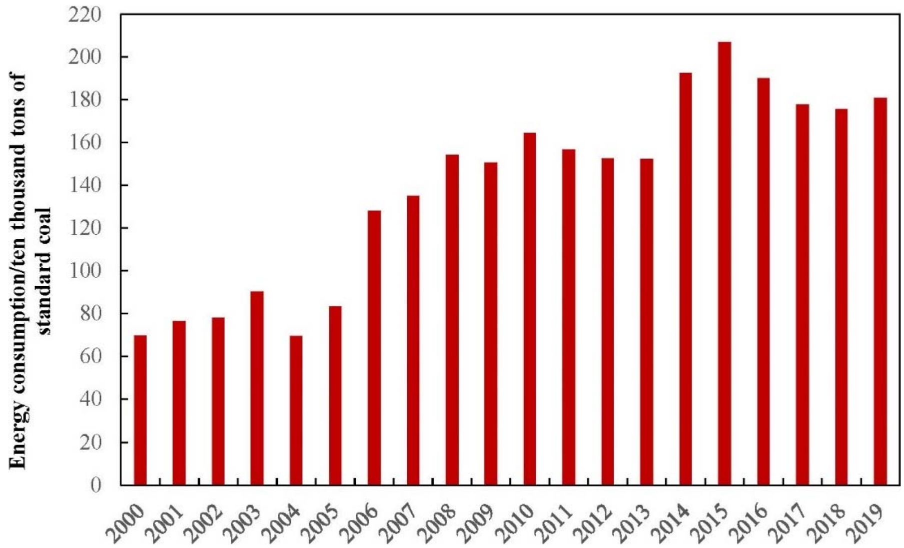

Figure 2.—Energy consumption of Chinese furniture manufacturing industry in the period from 2000 to 2019.

and heat energy to electricity and natural gas during the past two decades (Table 2).

Carbon dioxide emissions of the Chinese furniture manufacturing industry

Figure 3 presents the carbon dioxide emissions of the Chinese furniture manufacturing industry from 2000 to 2019. The carbon dioxide emissions generally exhibited a rising trend, increasing from 219.50 $\times$ 10,000 tons of CO_2 equivalent in 2000 to 850.68 $\times$ 10,000 tons of CO_2 equivalent in 2019. This is mainly due to the rapid development of the Chinese furniture industry during the past two decades. The evolution of the carbon dioxide emission levels can be divided into three stages. In the first stage (from 2000 to 2005), carbon dioxide emission levels were very low, and annual carbon dioxide emissions were $\sim$200 to 300 $\times$ 10,000 tons of CO_2 equivalent. In the second stage (from 2006 to 2013), carbon dioxide emissions levels increased to $\sim$400 to 540 $\times$ 10,000 tons of CO_2 equivalent per year. Compared with the previous stages, carbon dioxide emission levels were relatively high in the third stage (from 2014 to 2019), ranging between 785 and 850 $\times$ 10,000 tons of CO_2 equivalent. Previous research suggests that energy consumption has a positive significant influence on carbon dioxide emissions (Vujović et al. 2018). Thus, this trend can be explained by the increasing energy consumption and the change in energy structure for the Chinese furniture manufacturing industry in the past two decades.

Table 3 reports the contribution rates of the carbon dioxide emissions from different energy source types. Electricity and raw coal had a dominant influence on the carbon dioxide emissions of the Chinese furniture manu-

Table 2.—Percentages of different kinds of energy consumed in Chinese furniture manufacturing industry from 2000 to 2019.

	Raw coal	Coke	Natural gas	Liquefied natural gas	Diesel oil	Fuel oil	Gasoline	Liquefied petroleum gas	Heat energy	Electricity	Other energy
2000	53.66	1.46	0	0	5.38	1.38	8.37	0.76	6.87	21.99	0.14
2001	52.54	1.52	0	0	5.75	1.13	7.85	0.85	6.71	23.53	0.12
2002	53.61	1.43	0	0	6.73	1.37	8.28	1.08	8.93	18.42	0.18
2003	56.40	0.99	0	0	6.81	0.85	7.43	0.56	5.67	20.90	0.41
2004	36.93	1.70	0.49	0	12.57	0.43	4.82	2.62	1.96	36.86	1.61
2005	34.94	1.21	0.59	0	14.50	2.22	4.83	2.25	2.21	35.78	1.38
2006	43.26	3.09	0.45	0	9.52	5.87	3.50	1.54	1.81	27.32	3.44
2007	44.74	2.98	0.53	0	9.53	3.63	3.49	1.30	2.85	26.95	3.76
2008	42.14	2.12	3.34	0	13.03	0.27	3.84	1.70	2.09	27.79	3.49
2009	37.33	1.93	3.88	0	12.20	0.25	7.66	1.13	2.67	29.02	3.78
2010	32.64	2.67	2.75	0.13	12.88	0.51	7.37	1.15	2.53	33.27	3.88
2011	35.44	2.80	4.33	0.36	8.57	0.58	5.36	0.98	1.85	35.97	3.63
2012	35.13	2.41	5.28	0.52	7.33	0.30	5.09	0.93	1.69	36.90	4.29
2013	31.11	1.52	5.54	0.97	7.27	0.24	5.08	0.73	1.57	39.94	5.88
2014	19.19	0.84	4.86	2.41	5.54	0.19	3.76	0.51	1.50	56.77	4.40
2015	17.07	0.88	5.72	3.77	5.11	0.18	3.69	0.47	1.30	55.11	3.62
2016	15.14	0.73	6.85	2.20	4.52	0.22	3.55	0.49	1.74	62.01	2.53
2017	6.91	0.41	9.00	3.78	4.07	0.25	3.82	0.50	1.22	68.18	1.81
2018	1.84	0.45	9.59	1.95	3.18	0.13	2.67	0.42	1.81	76.23	1.69
2019	0.77	0.29	9.53	2.28	2.41	0.12	1.96	0.26	1.14	78.39	2.86

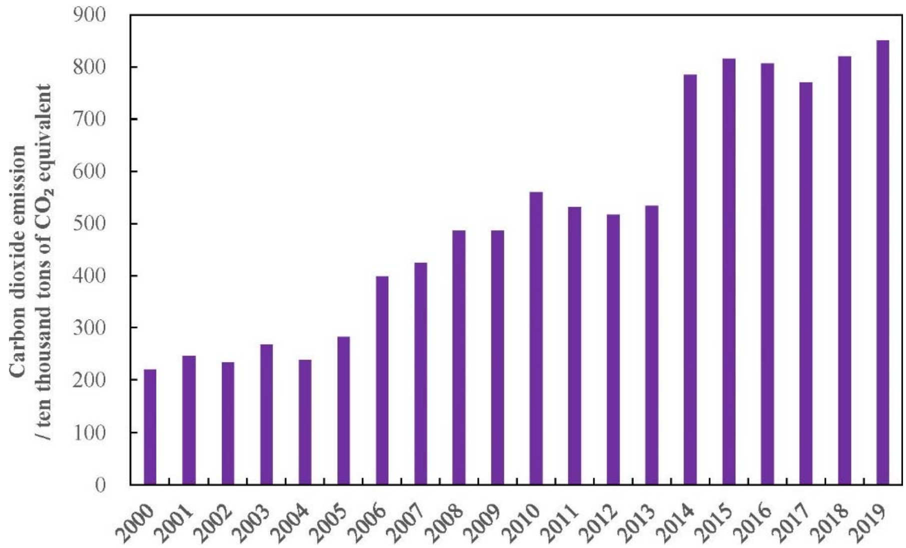

Figure 3.—Carbon dioxide emission of Chinese furniture manufacturing industry in the period from 2000 to 2019.

facturing industry over the past two decades. In particular, the percentage of carbon dioxide emissions from electricity rapidly increased from 38.71 percent to 92.32 percent. In contrast, the percentage of carbon dioxide emissions from raw coal exhibited a sharp decrease from 42.46 percent to 0.4 percent. Diesel oil, gasoline, heat energy, and natural gas contributed 4.93 percent, 3.01 percent, 2.84 percent, and 1.54 percent (a total of 12.32%) to the carbon dioxide emissions during this period. In general, the contribution rate of natural gas exhibited a slight upward trend, while that of gasoline showed a slight downward trend. The contribution rate of diesel oil and heat energy initially increased and subsequently decreased. As previously mentioned, the carbon dioxide emissions strongly depend on energy consumption. These results confirm the transformation of the energy structure within the Chinese furniture manufacturing industry.

Figure 4 depicts the carbon dioxide emission intensity of the Chinese furniture manufacturing industry in the period 2000 to 2019. The carbon dioxide emission intensity presented a downward trend, dropping from 9.50 tons of CO_2 per million dollars in 2000 to 1.73 tons of CO_2 per million dollars in 2019. From 2000 to 2005, the carbon dioxide emission intensity showed a dramatic decline, decreasing by 26.7 percent per year. Henceforth, the carbon dioxide emission intensity was slightly reduced, decreasing by 4.97 percent per year. These trends may be attributed to the following: (1) improvements in the energy efficiency; (2) progress in production technology; and (3) the upgrading of industrial structure. The carbon dioxide emission intensity can reflect the relationship between industrial

Table 3.—Percentages of carbon dioxide emission from different kinds of energy consumed in Chinese furniture manufacturing industry in the period from 2000 to 2019.

	Raw coal	Coke	Natural gas	Liquefied natural gas	Diesel oil	Fuel oil	Gasoline	Liquefied petroleum gas	Heat energy	Electricity	Other energy
2000	42.46	1.37	0	0	3.64	0.97	5.29	0.44	7.03	38.71	0.09
2001	41.45	1.39	0	0	3.81	0.77	4.85	0.48	6.72	40.46	0.08
2002	42.76	1.41	0	0	4.79	1.02	5.51	0.65	9.64	34.11	0.12
2003	42.92	0.97	0	0	4.88	0.64	4.98	0.35	6.17	39.08	0.01
2004	23.84	1.47	0.27	0	7.80	0.28	2.81	1.38	1.84	59.67	0.63
2005	22.88	1.04	0.31	0	9.10	1.46	2.84	1.21	2.10	58.56	0.50
2006	32.04	2.95	0.22	0	6.51	4.19	2.24	0.90	1.89	48.76	0.31
2007	34.13	2.79	0.25	0	6.45	2.57	2.21	0.75	2.92	47.52	0.41
2008	32.13	1.98	1.74	0	8.80	0.19	2.43	0.98	2.14	48.90	0.73
2009	29.75	1.77	1.96	0	8.04	0.17	4.72	0.64	2.67	49.86	0.44
2010	26.16	2.30	1.31	0.07	8.04	0.33	4.30	0.61	2.39	54.10	0.38
2011	25.08	2.43	2.08	0.19	5.36	0.38	3.14	0.52	1.75	58.75	0.32
2012	24.51	2.10	2.59	0.28	4.60	0.20	2.99	0.50	1.61	60.38	0.24
2013	22.91	1.28	2.63	0.50	4.42	0.15	2.89	0.38	1.45	63.23	0.16
2014	12.94	0.61	1.98	1.07	2.88	0.10	1.83	0.23	1.19	77.07	0.09
2015	11.63	0.66	2.42	1.73	2.76	0.11	1.86	0.22	1.06	77.51	0.04
2016	9.24	0.51	2.66	0.94	2.26	0.11	1.67	0.21	1.32	81.00	0.08
2017	4.03	0.28	3.43	1.54	2.00	0.13	1.76	0.21	0.90	85.66	0.08
2018	0.97	0.29	3.46	0.75	1.45	0.06	1.13	0.16	1.25	90.40	0.08
2019	0.40	0.18	3.43	0.88	1.09	0.05	0.83	0	0.78	92.32	0.04

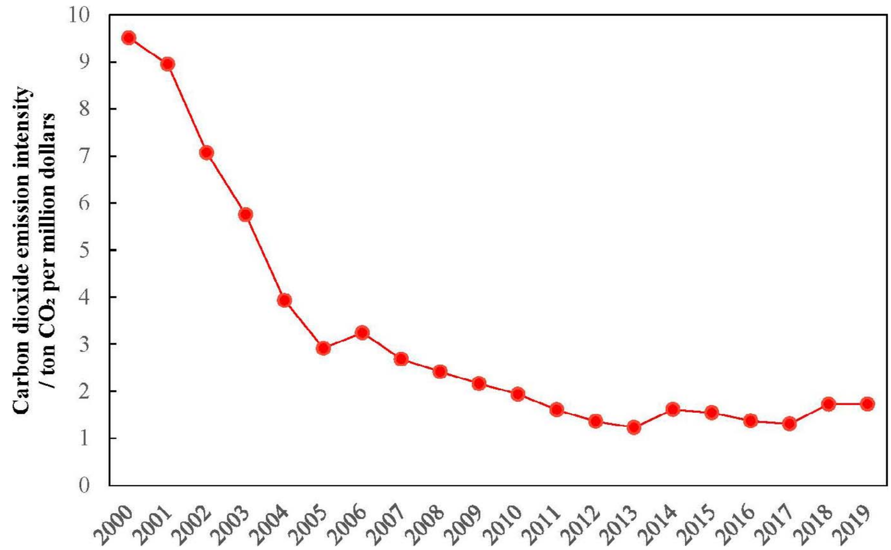

Figure 4.—Carbon dioxide emission intensity of Chinese furniture manufacturing industry in the period from 2000 to 2019.

development and carbon dioxide emissions (Wen and Wang 2020). Thus, the results in this paper indicate that the Chinese furniture manufacturing industry generally realized low-carbon development over the past two decades.

Discussion

Strategies to reduce carbon dioxide emissions from the Chinese furniture manufacturing industry

Although the carbon dioxide emissions of the Chinese furniture manufacturing industry are low, the sector still has the potential to further reduce emissions. Therefore, based on the results, we propose the following strategies for carbon dioxide emission reduction. (1) Promoting the use of electricity from renewable energy, which includes wind energy, nuclear energy, biomass energy, hydroelectric power, and nuclear power. (2) Encouraging furniture manufacturing enterprises to install photovoltaic cells in order to partially satisfy the electricity requirements for manufacturing processes. (3) Promoting industrial transformation and upgrading though measures such as the encouragement of low-carbon technological innovation and the elimination of backward production capacity. (4) Optimizing the transport modes for product delivery and material supply. For example, furniture manufacturing enterprises may prefer to use railway transportation and oceanic shipping. In addition, the conventional trucks used in road transportation can be replaced by cleaner vehicles. (5) Employing low-carbon raw materials (e.g., furniture manufacturing enterprises can use lower density wood composites because the carbon sequestered in wood composites is greater than the carbon emission in the manufacturing process; Puettmann 2022). Moreover, lower density wood composites can reduce the load on the cutting knives, resulting in less power used and lower carbon dioxide emissions. These recommendations provide reference for in-depth research on achieving carbon peak and carbon neutralization goals in the Chinese furniture manufacturing industry.

Limitations of the study

This study uses the IPCC Tier-2 method to estimate the carbon dioxide emissions of the Chinese furniture manufacturing industry at the national scale. Despite the progress made in this work, it has some limitations. In particular, there is a lack of in-depth investigation into factors influencing the carbon dioxide emissions from the Chinese furniture manufacturing sectors, such as energy efficiency, production technology, and industrial structure. Future research will focus on these to determine their impact on the carbon dioxide emissions from the Chinese furniture manufacturing sectors. Moreover, carbon dioxide emissions of the subdivision fields of the Chinese furniture manufacturing sectors cannot be quantified on account of unavailable data. However, this limit may be overcome with the development of China Statistical Database.

Conclusion

In this paper, we assessed the carbon dioxide emissions from the Chinese furniture manufacturing industry during the period 2000 to 2019 in order to improve the environmental performance. The carbon dioxide emissions exhibit an increasing trend, growing from 219.50 $\times$ 10,000 tons of CO_2 equivalent in 2000 to 850.68 $\times$ 10,000 tons of CO_2 equivalent in 2019. Electricity and raw coal exert a significant influence on carbon dioxide emissions, followed by diesel oil, gasoline, heat energy, and natural gas. The carbon dioxide emission intensity exhibits a decreasing trend, dropping from 9.50 tons of CO_2 per million dollars to 1.73 tons of CO_2 per million dollars in this period. In conclusion, the Chinese furniture manufacturing industry generally achieved low-carbon development over the past two decades.

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