Environmental Kuznets Curve of Carbon Emissions from China's Forest Products Industry and Decomposition of Factors Influencing Carbon Emissions

Bing Han and Jinzhuo Wu *

Carbon emissions from China's forest products industry were considered based on the data of 2001-2020. Then a carbon emissions Kuznets curve was constructed to judge the relationship between the economic development level and carbon emissions. The logarithmic mean Divisia index (LMDI) was used to analyze the influencing factors of carbon emissions. The carbon emissions from China's forest products industry showed a trend of rapid growth in the early stage and slow decline in the later stage, increasing from 19.46 million tonnes in 2001 to 54.18 million tonnes in 2020. Consumption of raw coal was the main reason for the increase in carbon emissions. There was an inverted-U relationship between the economic development level and carbon emissions, and the industry output value of CNY 3306.56 billion was the theoretical inflection point. The current economic development level of the industry was in the left-half part of the inverted "U" shape, indicating that carbon emissions from this industry will continue to increase with the increase of industrial output. Economic development was the key factor driving the increase of carbon emissions in the forest products industry, while the energy intensity was the key factor inhibiting the growth of carbon emissions.

DOI: 10.15376/biores.19.2.3390-3408

Keywords: Forest products industry; Carbon emissions; Environmental Kuznets curve; LMDI decomposition

*Contact information: School of Civil Engineering and Transportation, Northeast Forestry University, Harbin 150040 China; *Corresponding author: wjz@nefu.edu.cn*

INTRODUCTION

Currently, China is the largest emitter of carbon dioxide in the world with carbon emissions of 10.25 billion tonnes in 2020 (Liu 2023). To actively respond to global climate change and reduce carbon emissions, China announced that it will strive to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 (Yu and Xia 2021). The forest products industry is a secondary forestry industry mainly focusing on forest resources processing and manufacturing (Hu and Nie 2020). As one of the fundamental industries in China, it will give full play to the role of industry carbon storage and emission reduction, and assist the country in achieving carbon peak and carbon neutrality (Hou *et al.* 2022). The economic output value of the industry was CNY 2.9 trillion in 2020, accounting for 35.7% of the total forestry output value (Shen 2021). While achieving huge economic benefits, the characteristics of high input and high output in China's forest products industry also exposed increasingly serious environmental pollution problems (Xu and Wang 2010). In 2020, the carbon emissions of China's forest products industry reached 54.18 million tonnes (Shen *et al.* 2021). The report of the 20th National Congress of the

Communist Party of China proposed to establish and improve the high-quality development path featuring green and low-carbon recycling development (Shen 2021). Therefore, it is particularly important to reduce carbon emissions and achieve low-carbon development in China's forest products industry.

The environmental Kuznets curve (EKC) is a tool to measure the relationship between environmental quality and economic development level of a country or region (Atasoy 2017; Leal and Marques 2022). It refers to the hypothesis that there exists an inverted U-shaped relationship between environmental degradation and economic output. That is to say, pollution emissions increase and environmental quality declines in the early stages of economic growth, but beyond some level of economic output the trend reverses (Dinda 2004). Several studies have been conducted to analyze the relationship between carbon emissions and economic output. For example, Liu *et al.* (2011) established the environmental Kuznets curve of China's carbon dioxide emissions based on China's per capita income level, total carbon emissions, per capita carbon emissions, and carbon emission intensity from 1995 to 2007. They found that there existed an inverted U-shaped relationship between per capita income and per capita carbon emissions. Llanos *et al.* (2022) established the environmental Kuznets curve by selecting the energy consumption, carbon emissions and per capita income levels of 94 countries from 1971 to 2018, and found that the relationship between the carbon emissions and energy consumption growth of low- and middle-income countries supported the environmental Kuznets curve hypothesis. Wang *et al.* (2023) established the income level and carbon emission environmental Kuznets curve by considering the trade openness, human capital, renewable energy and natural resource rent factors of 208 countries from 1999 to 2018, and found that the income level and carbon emissions showed an inverted U-shaped curve on a global scale. In summary, most of the studies on environmental Kuznets curve either focused on the national or wider scale, whereas research on the relationship between carbon emissions and economic development in the forest products industry has been rarely documented. Observing the environmental Kuznets curve of carbon emissions from China's forest products industry and accurately estimating the curve shape and inflection point are of great significance to the formulation of emission reduction strategies for China's forest products industry.

Industrial carbon emissions are the result of long-term interactions of multiple factors. The Logarithmic Mean Divisia Index (LMDI) is one of the decomposition methods that has been widely used to decompose the influencing factors of carbon emissions (Liu and Li 2018; Hasan and Wu 2020; Koilakou *et al*. 2023). For example, Timilsina and Shrestha (2009) used the LMDI method to decompose the influencing factors of carbon emissions in the transportation industry of 12 Asian countries. They found that energy intensity and economic factors were the main driving factors of carbon emissions. Xu (2013) used the LMDI model to decompose the influencing factors of China's carbon emissions in various stages. It was found that the positive and negative influencing factors in each stage were basically the same, among which economic output value, urbanization level, and per capita GDP were the main driving factors. Liu and Wang (2022) used the LMDI decomposition method to study the driving factors of carbon emissions in China's manufacturing industry from 2000 to 2018. The results showed that both economic factors and industrial structure promoted carbon emissions, while energy intensity and energy structure inhibited carbon emissions. However, few studies were documented to analyze the influencing factors of carbon emissions from China's forest products industry.

Therefore, the goal of this study was to analyze the characteristics of carbon emissions from China's forest products industry, explore the relationship between the economic development level of China's forest products industry and carbon emissions, and quantitatively analyze the influencing factors of carbon emissions from China's forest products industry. The study results can help Chinese government effectively adjust and formulate corresponding emission reduction policies, and promote the green development of the forest products industry. Specifically, the objectives of the study are to: (1) calculate the carbon emissions and carbon emission intensity of China's forest products industry from 2001 to 2020 using the carbon emission coefficient method proposed by IPCC; (2) establish the environmental Kuznets curve to study the relationship between the carbon emissions from China's forest products industry and economic development level, and accurately estimate the curve shape and inflection point; and (3) identify the influencing factors of China's forest products industry using the LMDI decomposition method.

THEORETICAL ANALYSIS FRAMEWORK AND EXPERIMENTAL

Theoretical Analysis Framework

The development goals of the modern forestry industry are to be low-carbon, environmentally friendly, and achieving sustainable development (Li *et al.* 2021). The widespread application of wood products has enormous potential for carbon reduction and storage (Luo 2023). The comprehensive recycling of wood resources can effectively slow down the carbon dioxide cycle (Zhang *et al*. 2023). Comprehensively promoting the green, low-carbon, and circular development of the forestry industry is not only an inevitable requirement for achieving high-quality development in the industry, but also an important measure to help achieve the "dual carbon" goals.

In order to explore the relationship between the economic development level of China's forest products industry and carbon emissions and quantitatively analyze the influencing factors of carbon emissions, this study attempts to construct a structurally complete and logically clear theoretical analysis framework, as shown in Fig. 1.

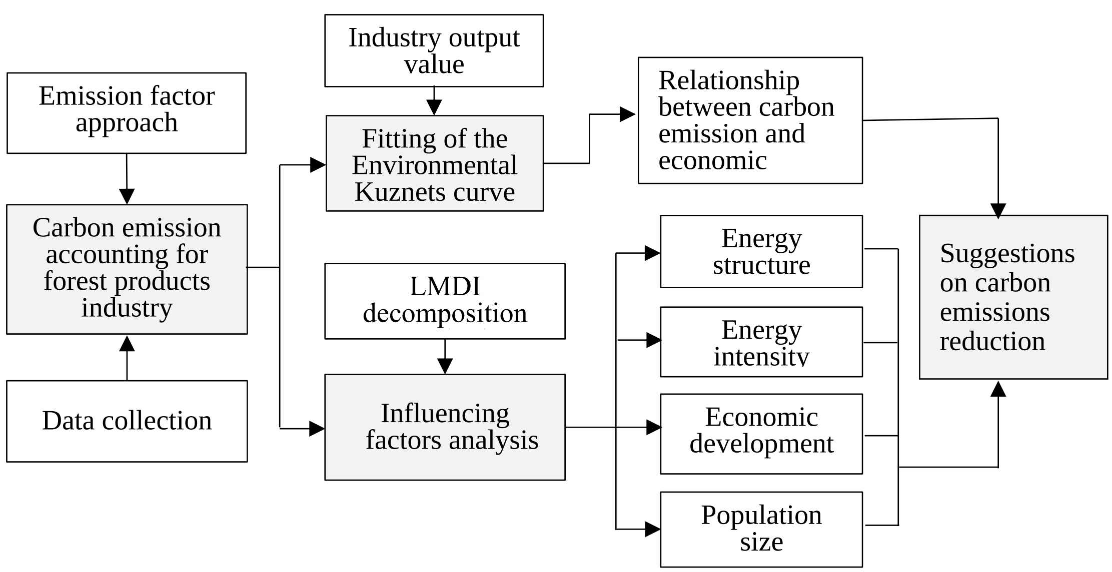

Fig. 1. Theoretical analysis framework

Three specific aspects are included, namely carbon emissions accounting from China's forest products industry, environmental Kuznets curve analysis, and the influencing factors of carbon emissions from China's forest products industry. The methods used in this study are detailed as follows.

Emission Factor Approach

The methods of accounting industry carbon emissions include three categories: emission coefficient method, mass balance method, and actual measurement method (Li *et al*. 2021; Chen and Wu 2022). Carbon emission coefficient generally refers to the carbon emission factor data based on the Guidelines for National Greenhouse Gas Inventories issued by the Intergovernmental Panel on Climate Change (IPCC) in 2019. Based on the availability of data and the accuracy of accounting results, this paper used carbon emission coefficient method to calculate the carbon emissions of China's forest products industry from 2001 to 2020. Carbon emission intensity refers to the carbon emissions generated by each unit of increase in industry output value, reflecting the relationship between economic output and carbon emissions in a certain period of time (Tian and Ma 2020). With the increase of industry output value, the carbon emissions show a downward trend, indicating that the industry has reached the level of low-carbon development.

The specific formulas for calculating carbon emissions and carbon emission intensity of forest products industry are expressed as follows,

$$C^t = \sum_{i=1}^{n} E_i^t \times \theta_i \times \delta_i \tag{1}$$

$$Y^t = C^t / X^t \tag{2}$$

where C^t represents the total carbon emissions of forest products industry in year *t*; E_i^t represents the consumption of energy i in year *t*; θ_i is the standard coal coefficient of energy *i*; δ_i is the carbon emission coefficient of energy *i*; X^t represents the total output value of forest products industry in year *t*, and Y^t represents the carbon emission intensity in year *t*. In this study, nine types of energy consumption including coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, natural gas, and electric power were selected to measure the energy consumption of forest products industry. Among them, the energy consumption from 2001 to 2020 was from China Energy Statistical Yearbook (2002-2021), the output value of forest products industry was from China Forestry and Grassland Statistical Yearbook (2002-2021).

Table 1. Conversion Coefficients of Standard Coal and Carbon Emission Coefficients

Energy	Conversion Coefficients of Standard Coal (kg standard coal)	Carbon Emission Coefficients (tonnes per tonne standard coal)
Coal (kg)	0.7143	0.7559
Coke (kg)	0.9714	0.855
Crude oil (kg)	1.4286	0.5857
Gasoline (kg)	1.4714	0.5538
Kerosene (kg)	1.4714	0.5714
Diesel (kg)	1.4571	0.5912
Fuel oil (kg)	1.4286	0.6185
Natural gas (m^3)	1.33	0.4483
Electricity (kWh)	0.1229	2.2132

The standard coefficient and carbon emission coefficient of different energy sources were from China Energy Statistical Yearbook and Guidelines for National Greenhouse Gas Inventories issued by the Intergovernmental Panel on Climate Change (IPCC) in 2019. The specific values are presented in Table 1.

Carbon Emission Environmental Kuznets Curve

In the 1990s, Grossman and Krueger proposed the inverted U-shaped hypothesis of the Environment Kuznets Curve, which has become a key tool for scholars to analyze the correlation between a country's economic development and environmental conditions (Xu *et al*. 2014; Gill *et al*. 2018; Liu and Huang 2023). The hypothesis holds that there is an inverted U-shaped relationship between the level of economic development and the degree of environmental pollution in a country. That is to say, before the economic development level reaches a certain critical value, the degree of environmental pollution increases with the improvement of economic development level. After reaching the critical value, the degree of environmental pollution gradually decreases with economic growth due to more efficient use of natural resources and energy (Voumik *et al*. 2022). In consideration of the heterogeneity of carbon emissions in different industries, there may be a linear or nonlinear relationship between industrial CO_2 emissions and industrial scale simultaneously. Therefore, referring to the existing studies (Du et al. 2017; Tian and Ma 2020), this paper established a general carbon emission environmental Kuznets curve model to reflect the relationship between the total carbon emissions and the economic development of forest products industry. The specific equation of the model is shown as follows:

$$C^t = \alpha + \rho_1 X_t + \rho_2 X_t^2 + \rho_3 X_t^3 + \mu \tag{3}$$

where α represents the intercept term; C^t denotes the total carbon emissions of forest products industry in year *t*; X_t denotes the forest products industry output value in year *t*; μ denotes the random disturbance term; and ρ_1, ρ_2, and $\rho_3$represent the coefficients to be estimated of the first, second and third terms, respectively. To overcome the heteroscedasticity of the original data, the natural logarithm (*Ln*) form of each variable was used to solve the model. The data of carbon emissions and output value were from the China Statistical Yearbook (2002-2021), China Energy Statistical Yearbook (2002-2021) and China Forestry and Grassland Statistical Yearbook (2002-2021).

The criteria for judging the EKC curve of carbon emissions are as follows (Zhao *et al*. 2021): (1) When ρ_1>0, ρ_2=ρ_3=0, there is a linearly positive correlation between total carbon emissions and economic level; when ρ_1<0, ρ_2=ρ_3=0, the relationship is linearly negative correlation. (2) When ρ_1>0, ρ_2<0, ρ_3=0, the relationship between total carbon emissions and economic level is an inverted U-shaped curve; when ρ_1<0, ρ_2>0, ρ_3=0, the relationship is a U-shaped curve. (3) When ρ_1>0, ρ_2<0, ρ_3>0, the relationship between total carbon emissions and economic level is a N-shaped curve; when ρ_1<0, ρ_2>0, ρ_3<0, the relationship between them is an inverted N-shaped curve. Based on the carbon emission environmental Kuznets curve model, this paper explored whether there is a carbon emission inflection point in China's forest products industry and the time path required to reach the inflection point, which can lay a foundation for the low-carbon development of the forest products industry.

LMDI Decomposition Method

Index decomposition analysis is one of the most widely used methods in the decomposition of carbon emission factors, including the pull index decomposition method and the Divisia index decomposition method (Hoekstra and van den Bergh 2003; de Boer and Rodrigues 2019). The former will generate residual terms when decomposing various variable factors, proving that the model has not fully explained the parts that affect the changes of carbon emissions. The latter will not generate residual terms that the model cannot explain, and can effectively deal with the zero-value phenomenon (Ang 2005). Therefore, the Logarithmic Mean Divisia Index decomposition model (LMDI) was used to explore the influencing factors of carbon emissions in China’s forest products industry.

The LMDI model can calculate the contribution of various factors affecting the complex structure by establishing an extended Kaya identity, which lays the foundation for proposing subsequent appropriate policies (Ang 2005). By calculating the contribution value of each influencing factor, one can intuitively find the impact of each factor on carbon emissions. In this study, the influencing factors of carbon emissions were decomposed into five factors: carbon emission coefficient, energy structure, energy efficiency, economic development level and population size, as shown in Eq. (4),

$$\begin{aligned} C &= \sum_{i=1}^{n} C_i = \sum_i \frac{C_i}{E_i} \times \frac{E_i}{E} \times \frac{E}{G} \times \frac{G}{P} \times P \\ &= \sum_{i=1}^{n} r_i \times s_i \times e \times m \times P \end{aligned} \tag{4}$$

where C represents carbon emissions of China’s forest industry in certain year; C_i represents carbon emissions of energy *i* in the year; E_i indicates the consumption of energy *i* in the year; *E* represents total energy consumption of the year ; *G* represents gross domestic product (GDP); *P* represents population factor, specifically the population at the end of the year ; r_i represents the carbon emission coefficient factor, indicating the carbon emissions of the unit *i* energy consumption; s_i represents the energy consumption structure factor, indicating the proportion of the energy *i* consumption to total energy consumption; *e* represents energy consumption intensity factor, which represents the energy consumption per unit of GDP; and *m* represents the economic level factor based on per capita GDP. The energy consumption data were from China Energy Statistical Yearbook (2002-2021), and the gross domestic product (GDP) and the population were from China Statistical Yearbook (2002-2021).

The ratio of carbon emissions at the end of the reporting period to the carbon emissions in the base period was used to represent the change of carbon emissions, and the contribution of each influencing factor to the emission reduction of forest products industry was judged by the positive and negative values of the change. Based on the LMDI model, the change of carbon emissions between the reporting period and the base period was decomposed into four parts, including the contributions of energy structure (ΔC_s), energy intensity (ΔC_e), economic level (ΔC_m), and population size (ΔC_p) (Eq. 5). The calculation formula of the contribution of the four influencing factors is shown in Eqs. (6) to (9).

$$\Delta C_t = C_t - C_0 = \sum_i \left(\Delta C_s + \Delta C_e + \Delta C_m + \Delta C_P \right) \tag{5}$$

$$\Delta C_s = \sum_i^n L\left(C_i^t, C_i^0\right) In \frac{s_i(t)}{s_i(0)} \tag{6}$$

$$\Delta C_e = \sum_i^n L\left(C_i^t, C_i^0\right) In \frac{e_i(t)}{e_i(0)} \tag{7}$$

$$\Delta C_m = \sum_i^n L\left(C_i^t, C_i^0\right) In \frac{m(t)}{m(0)} \tag{8}$$

$$\Delta C_p = \sum_i^n L\left(C_i^t, C_i^0\right) In \frac{p(t)}{p(0)} \tag{9}$$

Among them, the implication of $L\left(C_i^t, C_i^0\right)$ is defined as follows:

$$L(C_i^t,\ C_i^0) = \begin{cases} \dfrac{C_i^t - C_i^0}{\ln(C_i^t / C_i^0)}, & C_i^t \neq C_i^0 \\ C_i^t \text{或} C_i^0, & C_i^t = C_i^0 \end{cases} \tag{10}$$

The LMDI decomposition model not only can be used to calculate the contribution value of various influencing factors on carbon emissions in forest products industry, but also it can be used to calculate the contribution rate of each factor affecting carbon emissions. The ratio of carbon emissions in the reporting period to carbon emissions in the base period was used to represent the total utility of carbon emissions influencing factors. If the value of index ranges from 0 to 1, it indicates that the factor has the effect of inhibiting carbon emissions; on the contrary, if the index value is greater than 1, it shows that this factor can promote carbon emissions. According to the LMDI model, the total effect (D_t) is decomposed into the product of the contribution rate of each influencing factor (Eq.11). Among them, D_s, D_e, D_m, and D_p represent the contribution of energy structure factor, energy efficiency, economic level and population size, respectively. The calculation formula of the contribution rate of each factor is shown in Eqs. (12) - (16).

$$D_t = \frac{C_t}{C_0} = D_s \times D_e \times D_m \times D_p \tag{11}$$

$$D_s = \exp\left[\sum_i \frac{L_i}{\left(C^t/C^0\right)/\left(InC^t - InC^0\right)} In \frac{\left(E_i/E\right)^t}{\left(E_i/E\right)^0}\right] \tag{12}$$

$$D_e = \exp\left[\sum_i \frac{L_i}{\left(C^t/C^0\right)/\left(InC^t - InC^0\right)} In \frac{\left(E/G\right)^t}{\left(E/G\right)^0}\right] \tag{13}$$

$$D_m = \exp\left[\sum_i \frac{L_i}{\left(C^t/C^0\right)/\left(InC^t - InC^0\right)} In \frac{\left(G/P\right)^t}{\left(G/P\right)^0}\right] \tag{14}$$

$$D_p = \exp\left[\sum_i \frac{L_i}{\left(C^t/C^0\right)/\left(InC^t - InC^0\right)} In \frac{\left(P\right)^t}{\left(P\right)^0}\right] \tag{15}$$

$$L_i = \left(C_i^t - C_i^0\right)/\left(InC_i^t - InC_0^t\right) \tag{16}$$

RESULTS AND DISCUSSION

Carbon Emission Characteristics of China's Forest Products Industry

Total carbon emissions from forest products industry

The total carbon emissions of China's forest products industry from 2001 to 2020 are shown in Fig. 2. The carbon emissions of China's forest products industry during the study period showed a trend of rapid growth in the early stage and slow decline in the later stage. The carbon emissions in 2020 were about three times that of 2001, with an average annual growth rate of 5.54%. During the period of 2001-2013, the carbon emissions rapidly increased from 19.46 million tonnes in 2001 to the peak value of 58.42 million tonnes in 2013, with an annual growth rate of 9.59%. Since 2014, the carbon emissions had showed a slow downward trend with an average annual reduction of 0.60 million tonnes.

Carbon emissions from China's forest products industry initially decreased in 2014 and continued to decrease in the following two years. The Chinese government started to optimize and adjust its industrial structure in order to eliminate some outdated production capacity (Wang and Liu 2016). With the transformation and upgrading of the national energy structure, China also vigorously developed clean energy and renewable energy to reduce carbon emissions.

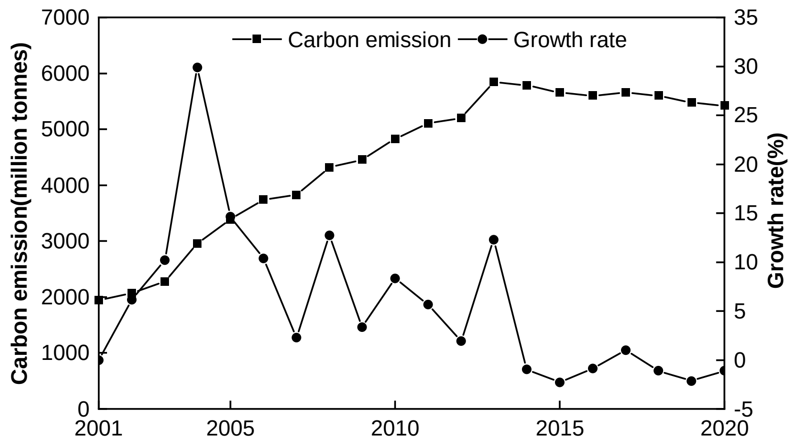

Fig. 2. The trend of total carbon emissions of forest products industry in China from 2001 to 2020

The carbon emissions of China's forest products industry by subdivided industries from 2001 to 2020 is shown in Fig. 3. The carbon emissions of the three sub-sectors of China's forest products industry showed an overall upward trend, with paper and paper products industry being the largest sources of carbon emissions. Within the study period, the proportion of emissions from the paper and paper products industry decreased from 84.86% in 2001 to 78.56% in 2020, decreasing by 6.3%. The trend of change was completely consistent with the total carbon emissions of the industry, indicating that the paper and paper products industry had the greatest contribution to the pollution of the forest products industry. Man *et al*. (2020) pointed out that paper industry was one of the main carbon emission industries in China. Therefore, it is necessary to reduce the carbon emissions of China's paper industry in order to achieve the low-carbon and sustainable development goals of China's economy and society. The furniture manufacturing industry had the smallest contribution to environmental pollution, which slowly increased from 3.48% in 2001 to 6.38% in 2020, an increase of about 3%. Except for the decrease in 2002, 2004, and 2008, all other years had maintained slow growth. The contribution of wood processing and wood, bamboo, rattan, palm, and grass product industry to environmental pollution was second only to paper and paper products industry. During the study period, its carbon emissions showed a slow upward trend in the early stage (2001-2014), followed by a slow decline and then maintained at around 15%. The output value of the three subdivided sectors during 2001 and 2020 is shown in Fig. 4. Wood processing and wood, bamboo, rattan, palm, and grass products accounted for the largest proportion of the total output value, even though the proportion dropped from 75.32% in 2001 to 46.74% in 2020. The furniture manufacturing industry had the smallest contribution, accounting for only 16.67% to 22.54% of the total industry output value, with a growth rate of only about 6%. The impact of paper and paper products industry output value was second only to wood processing and wood, bamboo, rattan, palm, and grass product industries. The proportion of output value increased from 8.01% in 2001 to 30.71% in 2020, with an increase of 22.70%. Based on the carbon emissions and output value, the three subsections showed different development trends, only the furniture manufacturing industry showed increasing trends in both aspects. Further analysis on the relationship between carbon emissions and output value will be analyzed in the subsequent analysis.

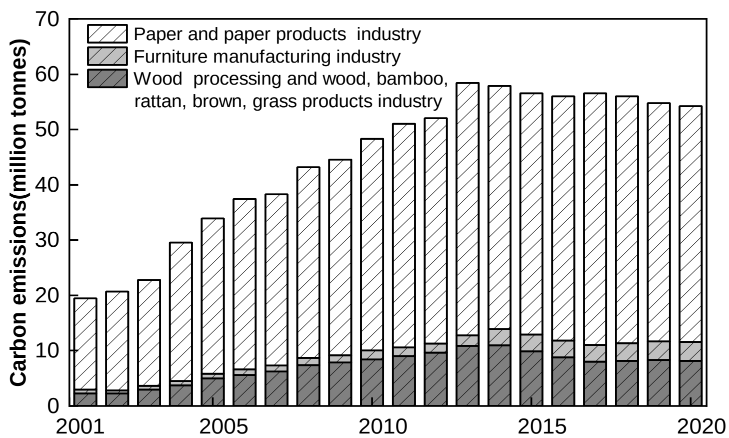

Fig. 3. Carbon emissions of China's forest products industry by subdivision

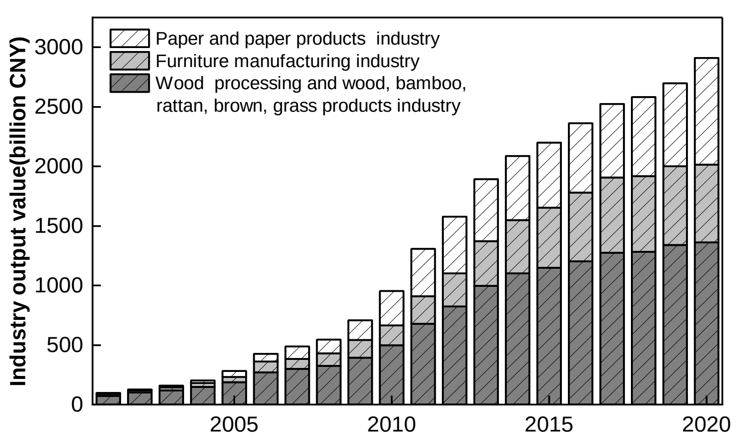

Fig. 4. Output value of China's forest products industry by subdivision

Carbon emissions of forest products industry by different energy sources

The carbon emissions of China's forest products industry by major energy sources from 2001 to 2020 are illustrated in Fig. 5. Raw coal and electricity were the main sources of carbon emissions in China's forest products industry, with an average proportion of 50.4% and 46.73%, respectively. Both of them showed a trend of fluctuation, with the proportion fluctuating around 50%. The total proportion of the other seven types of energy was less than 3%. From 2001 to 2016, the proportion of carbon emissions from raw coal was the largest, with an average of 52.77%, followed by electricity 44.57%. The former showed a slow downward trend overall, while the latter showed an overall upward trend. In addition, except for a slight fluctuation in the proportion of carbon emissions from natural gas, the proportion of carbon emissions from the other six types of energy remained almost unchanged. Since 2016, the proportion of raw coal had rapidly decreased from 47.9% to 35.75%, and the proportion of carbon emissions from electricity had significantly increased from 49.66% to 60.39%. Meanwhile, the proportion of natural gas had significantly increased, reaching 3% in 2020, which was nearly tripled compared to 2001.

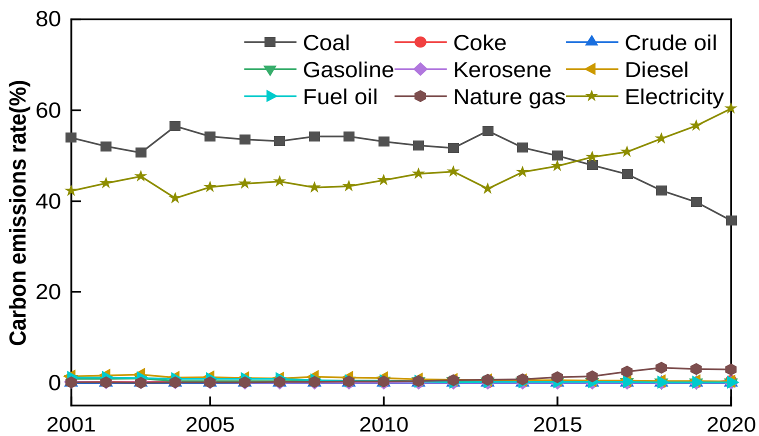

Fig. 5. Carbon emissions trends of different energy sources in China's forest products industry

Carbon Emission Intensity and Carbon Emission Kuznets Curve of China's Forest Products Industry

Carbon emission intensity of forest products industry

The characteristics of carbon emission intensity of China's forest products industry from 2001 to 2020 are shown in Fig. 6. Overall, the carbon emission intensity showed a downward trend, decreasing from 2.02 kg CNY^{-1} in 2001 to 0.29 kg CNY^{-1} in 2020. Except for a slight rebound in carbon emission intensity in 2004 and 2008, the carbon emission intensity in all other years had decreased. The decline processing can be divided into three stages. In the first stage (2001-2003), the carbon emissions per unit output value rapidly decreased, with an average annual decrease of 0.197 kg CNY^{-1}. In the second stage (2004-2008), the decline rate of carbon emission intensity was the most significant, with an average annual decrease of 0.21 kg CNY^{-1}. Since 2006, the carbon emission intensity of China's forest products industry had started to be less than 1.0, which indicated that for every unit increase in economic output value, the industry's carbon emissions correspondingly decreased. In the third stage (2009-2020), carbon emission intensity decreased slowly and remained at a relatively low level, with an average annual decrease of 0.016 kg CNY^{-1}, reaching 0.29 kg CNY^{-1} by 2020.

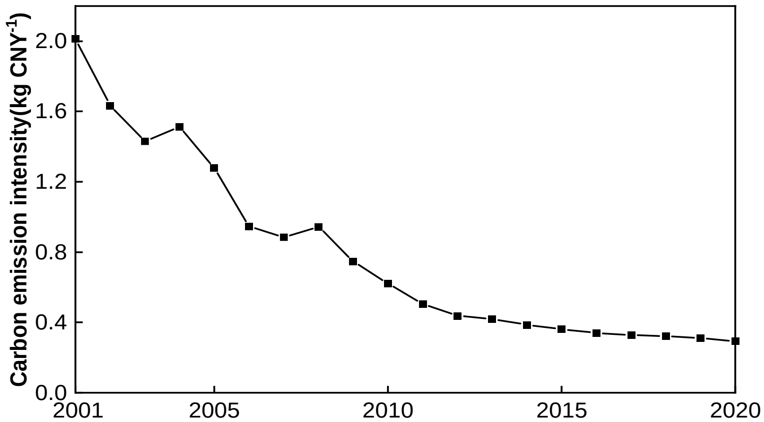

Fig. 6. Carbon emission intensity of China's forest products industry from 2001 to 2020

Carbon emissions Kuznets curve of forest products industry

The carbon emissions and industrial output value of China's forest products industry varied with time from 2001 to 2020. In order to ensure the fitting degree of the model, the unit root test on Ln*C* and Ln*X* was conducted. The results showed that there was no unit root for the two variables at a 5% confidence level, and both of them were integral sequence with the same order, which means that the two variables passed the stationary test and can be used to establish the Kuznets curve model.

The Kuznets curve relationship between the output value and carbon emissions for China's forest products industry from 2001 to 2020 was analyzed and tested using SPSS 26.0. The optimal model was then established based on the significance of the regression coefficients and the fit goodness. The fitting results are shown in Table 2.

Table 2. Fitting Results of the Kuznets Curve

Curve	α	ρ_1	ρ_2	ρ_3	R^2	F
Bout	5.238	0.354			0.946	315.161***
Conic	-1.614	1.998	-0.096		0.986	603.131***
Cubic	0.582	1.189	0.0003	-0.004	0.966	515.705***

The quadratic regression curve achieved the highest goodness of fit (R^2=0.986), and both of the regression coefficients (ρ_1, ρ_2, ρ_3) were significant at the 1% level. Therefore, the regression equation of the environment Kuznets curve for China's forest products industry can be established as follows, where *X* represents the output value of forest products industry in the year, and *C* represents the total carbon emissions of forest products industry in the year.

$$LnC = -1.614 + 1.998LnX - 0.096Ln^2X \tag{17}$$

The Kuznets curve regression results are illustrated in Fig. 7. It can be seen that with the increase of industry output value, the growth rate of carbon emissions gradually slowed down, and the curve showed a slow growth trend, resulting in the gradual decrease of carbon emissions per unit of output value. The relationship between the carbon emission of China's forest products industry and the level of economic development of the industry is close to the inverted-U shape. Tian and Ma (2020) analyzed the relationship between the output value and carbon emissions of 16 industrial sectors in China based on the data of

1984-2016, and also found that there were inverted U-shaped relationships between the output value and carbon emissions for wood processing and wood, bamboo, rattan, palm, and grass product industry, furniture manufacturing industry, and papermaking and paper product manufacturing industry. In addition, the Kuznets curve in this study is consistent with the trend of carbon emission intensity, indicating that the environmental Kuznets curve of China's forest products industry can better simulate the relationship between China's forestry economic development and environmental quality. Therefore, this study conforms to the hypothesis of the environmental Kuznets curve, indicating that with the continuous improvement of the output value in China's forest products industry, the environmental quality of the industry will undergo a development stage of first deteriorating and then improving, and the conclusion is robust.

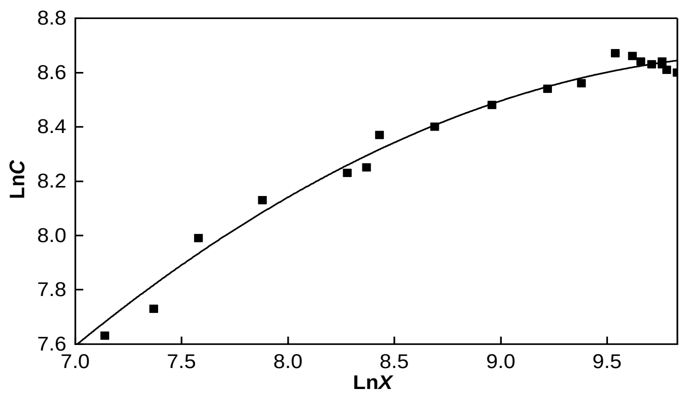

Fig. 7. Environmental Kuznets curve of carbon emissions of forest products industry in China

The turning point of the inverted "U" curve in Fig. 7 was calculated by taking the derivative of the regression equation. Results showed that the theoretical turning point of carbon emissions from China's forest products industry will be at the industry output value of CNY 3306.56 billion. At that time, the carbon emissions of China's forest products industry will reach 66.34 million tonnes. Looking at the current economic development level of China's forest products industry, it is found that China is currently located in the left half of the inflection point and has not yet reached the highest level of industry development, but is close to its peak. In this stage, China's forest products industry is characterized by high investment, high energy consumption, high pollution due to the extensive development mode. Predictably, the carbon emissions of China's forest products industry will continue to increase in the short term with the increase of economic output value and it is necessary to continuously promote energy conservation, emission reduction, and green sustainable development in the forest products industry in order to achieve the dual carbon goals.

Decomposition of Influencing Factors of Carbon Emissions in China's Forest Products Industry

The contribution values of various influencing factors to carbon emissions from China's forest products industry from 2001 to 2020 are shown in Table 3. The decomposition result conforms to Eq. 5, which successfully verifies the correctness of the LMDI decomposition results. The overall carbon emissions from China's forest products industry increased by 34.72 million tonnes, with energy structure contributing 6.17 million tonnes, economic development contributing 55.11 million tonnes, and population size contributing 3.35 million tonnes. Only the contributing value of energy intensity was negative, decreasing by 29.91 million tonnes. Therefore, economic development was the main factor promoting the increase of carbon emissions from China's forest products industry, and energy intensity factors played a restraining role in carbon emissions from forest products industry. The effect became increasingly significant over time.

Table 3. Decomposition of Influencing Factors on Carbon Emissions from China's Forest Products Industry (Unit: million tonnes)

Year	Energy structure Effect	Energy intensity effect	Economic development effect	Population size effect	Gross effect
2001-2002	0.29	-1.21	1.99	0.13	1.20
2002-2003	0.61	-1.90	4.35	0.26	3.32
2003-2004	-0.25	1.95	7.96	0.44	10.11
2004-2005	0.30	1.87	11.64	0.63	14.44
2005-2006	0.54	0.39	16.22	0.81	17.95
2006-2007	0.67	-3.69	20.86	0.96	18.80
2007-2008	0.32	-3.36	25.54	1.18	23.68
2008-2009	0.44	-5.15	28.50	1.35	25.13
2009-2010	0.86	-7.44	33.7	1.57	28.85
2010-2011	1.37	-9.96	38.35	1.81	31.58
2011-2012	1.54	-12.18	41.13	2.08	32.57
2012-2013	0.42	-9.99	46.10	2.43	38.96
2013-2014	1.59	-13.93	48.08	2.65	38.39
2014-2015	1.91	-16.47	48.84	2.78	37.06
2015-2016	2.54	-1932.63	50.37	2.99	36.57
2016-2017	2.72	-22.33	53.55	3.18	37.12
2017-2018	3.67	-25.74	55.32	3.27	36.52
2018-2019	4.66	-28.58	55.90	3.34	35.32
2019-2020	6.17	-29.91	55.11	3.34	34.72

The contribution rates of the four different influencing factors are shown in Fig. 8. It is noted that the level of economic development, energy structure, and population size had promoted the rapid growth of carbon emissions from China's forest products industry to varying degrees. Of these, the economic development factor played the most significant role. As a high energy consuming and high input industry, the extensive economic development of China's forest products industry increased environmental costs significantly (Shen 2020). The energy structure basically promoted carbon emissions, and its promotion intensity even surpassed the population size during 2017-2020. According to the contribution rates of carbon emissions from China's forest products industry, the ranking of factors driving the increase of carbon emissions from China's forest products industry were as follows: economic development level>energy structure>population size. The overall performance of energy intensity was a significant inhibitory effect, which exhibited a promoting effect in the early stage, then rapidly transformed into an inhibitory effect and remained at a high level. In the similar studies, energy intensity was also found to be the main restraining factor of China's carbon emissions (Yang *et al.* 2020). In summary, economic development factor was the determining factor for carbon emissions growth. It is expected that China's economic development level will continue to maintain high-speed growth from a long-term perspective, so it is necessary to further adjust energy structure and improve technological level in order to achieve the goal of green and low-carbon development of the forest products industry.

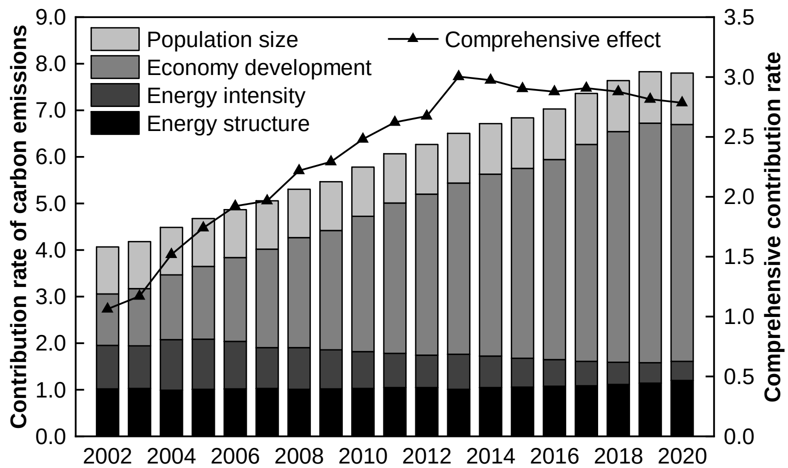

Fig. 8. Contribution rates of different factors to carbon emissions from China's forest products industry

Effect of energy structure on carbon emissions from forest products industry

The energy structure factor mainly promoted the carbon emissions of China's forest products industry, and its influence was second only to economic development factor. The contribution rate of energy structure ranged between 0.99 and 1.20, with an average of 1.05, which generally showed a weak promotion effect. The minimum contribution rate was 0.99 in 2003-2004, and the maximum was 1.20 in 2019-2020. Since 2013, the contribution rate had significantly increased over time until reaching its peak.

It is known that raw coal is the main energy consumed by China's forest products industry, followed by natural gas and electricity. Affected by national policies, the proportion of raw coal consumption decreased from 73.6% in 2001 to 57.3% in 2020, and the proportion of electricity and natural gas energy consumption increased from 19.7% to 33.1%, and from 0.2% to 8%, respectively. While reducing the consumption of raw coal, clean energy such as electricity and natural gas increased significantly. The main energy consumed by China's forest products industry is undergoing a transition from traditional fossil fuel energy to clean energy. Therefore, the optimization and upgrading of energy structure will have a significant impact on the contribution rate of carbon emissions from China's forest products industry.

Effect of energy intensity on carbon emissions from forest products industry

Energy intensity was the dominant factor of restraining carbon emissions from China's forest products industry. The maximum contribution rate was 0.94, the minimum was 0.41, and the average was 0.75. All values were less than 1.0. The inhibitory effect of energy intensity can be divided into two stages. In the first stage (2001-2003), the contribution rate of energy intensity decreased slightly from 0.94 to 0.91. In the second stage (2006-2020), the contribution rate decreased significantly from 1.01 to 0.41, with an average annual decrease of 0.05. Overall, the inhibitory effect of energy intensity on carbon emissions from China's forest products industry significantly increased with the development and progress of society. Meanwhile, the energy consumption per unit of GDP output continued to decrease, leading to a decrease in energy carbon emissions. Although there was a slight increase in the contribution rate of energy intensity between 2003 and 2006, which promoted carbon emissions from the forestry industry in the short term, the driving effect was still not significant. Therefore, energy intensity had a significant inhibitory effect on the comprehensive carbon emissions of the forestry industry. It is important to improve the technological level of China's forest products industry in order to achieve the goal of reducing energy intensity, and ultimately realizing green and low-carbon development of the forest products industry.

Effect of economic development on carbon emissions from forest products industry

Economic development was the determining factor for the growth of carbon emissions from China's forest products industry. The maximum contribution rate was 5.15 in 2019, the minimum was 1.10 in 2001, and the average contribution rate was 3.75. The driving effect can be divided into two stages. The first stage was from 2001 to 2019. The contribution rate of economic development ranged between 1.10 and 5.19, and the pulling effect was extremely significant and continued to increase over time. The second stage was from 2019-2020. Although the contribution rate of economic development from 2019 to 2020 decreased by 0.08 compared to 2018-2019 and the driving effect slightly weakened, it still showed a significant promoting effect. With the rapid development of the economy and the improvement of people's living standards, the energy consumption of China's forestry industry is constantly increasing, thereby increasing the carbon emissions of the industry.

Effect of population size on carbon emissions from forest products industry

The factor of population size promoted the growth of carbon emissions from China's forest products industry during the period of 2001-2020, and its contribution to carbon emissions in forest products industry was relatively stable. The contribution rate ranged between 1.01 and 1.10 with an average of 1.04 and the pulling effect of population increased slowly over time. Compared to the factor of economic development, its driving effect was not significant. Residents are the main energy users in China, and the expansion of population size inevitably led to an increase in the demand for various forest products, resulting in an increase in carbon emissions from China's forest products industry. Therefore, it is necessary to enhance people's environmental awareness and guide residents' consumption of forest products towards green and low-carbon development.

Limitations and Future Research

The forest products industry, as a fundamental industry featuring high input, high output, high energy consumption, and high emissions, supports the rapid development of China's forest products industry. Reducing its carbon emissions can promote the green development of the industry. In this study, the carbon emissions in China's forest products industry and its sub-sectors were calculated, the relationship between the economic development level of the forest products industry and carbon emissions was analyzed, and the promoting and inhibiting factors that affected the carbon emissions of the forestry industry were identified.

It should be noted that there are also some limitations in this study. It is worth noting that only five influencing factors were considered in the LMDI decomposition model and the impacts of other factors were not verified. Future research can be conducted by analyzing the influencing factors of carbon emissions using different methods, and more influencing factors can be added into the models in order to increase the robustness of the study results. In addition, it is necessary to apply medium to long-term forecasting methods to predict the carbon emissions from China's forest products industry and make comprehensive analysis with the results of the environmental Kuznets curve.

CONCLUSIONS

1. During the study period of 2001-2020, the carbon emissions of China's forest products industry showed an overall growth trend, increasing from 19.46 million tonnes in 2001 to 54.18 million tonnes in 2020. Carbon emissions increased rapidly during 2001-2013 due to the extensive use of raw coal. Since 2014, the use of clean energy natural gas and electricity had gradually replaced fossil energy, leading to the reduction of carbon emissions, which indicated that the carbon emissions generated by the forest products industry can be reduced by adjusting the energy structure. Papermaking and paper products industry contributed the most to carbon emissions, followed by wood processing and wood, bamboo, rattan, brown, grass products industry and furniture manufacturing industry. In the future, it is suggested to accelerate the construction of a low-carbon industrial structure system through technological improvement and capacity elimination to promote industrial transformation and realize low-carbon development of the industry.
2. The relationship between carbon emissions and industrial output value of China's forest products industry showed an inverted "U" shape, which was consistent with the hypothesis of carbon emission environmental Kuznets curve. The theoretical turning point of China's forest products industry will be at the industry output value of CNY 3306.56 billion and the corresponding peak value of carbon emissions is 66.34 million tonnes. The development level of China's forest products industry up to this point has been located in the left half of the curve, indicating that the carbon emissions from China's forest products industry will continue to increase with the increase of industrial output in the future.
3. During the study period, economic development factor, energy structure factor, and population factor all had positive impacts on the carbon emissions of China's forest products industry. Among them, economic development factor had the greatest impact on carbon emissions, followed by energy structure and population size. Energy intensity was decisive factor to curb the growth of carbon emissions. In terms of impact intensity, economic development factor > energy intensity factor > energy structure factor > population factor. Therefore, it is important to strengthen the research and development of new energy technologies, adjust energy structure, and reduce energy intensity in order to slow down the growth rate of carbon emissions from China's forest products industry.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Key Research Project for Economic and Social Development in Heilongjiang Province (22202).

REFERENCES CITED

Ang, B. W. (2005). "The LMDI approach to decomposition analysis: a practical guide," *Energy Policy* 33(7), 867-871. DOI: 10.1016/j.enpol.2003.10.010

Atasoy, B. S. (2017). "Testing the environmental Kuznets curve hypothesis across the US: evidence from panel mean group estimators," *Renewable and Sustainable Energy Reviews* 77, 731-747. DOI: 10.1016/j.rser.2017.04.050

Chen, Z. L., and Wu, J. Z. (2022). "Evolution of logistics industry carbon emissions in Heilongjiang Province China," *Sustainability* 14(15), 9758. DOI:10.3390/su14159758

De Boer, P. and Rodrigues, J. F. D. (2019). "Decomposition analysis: When to use which method?," *Economic Systems Research* 32(1), 1-28. DOI: 10.1080/09535314.2019.1652571

Dinda, S. (2004). "Environmental Kuznets curve hypothesis: A survey," *Ecological Economics* 49(4), 431-455. DOI: 10.1016/j.ecolecon.2004.02.011

Du, Q., Feng, X., and Sun, Q. (2017). "Study on relationship between carbon emissions and economic development in municipal construction industry: A case study of Xi'an," *Environmental Engineering* 35(2), 174-178. DOI: 10.13205/j.hjgc.20170203

Gill, A. R., Viswanathan, K. K., and Hassan, S. (2018). "The Environmental Kuznets Curve (EKC) and the environmental problem of the day," *Renew. Sustain. Energy Rev*. 81, 1636-1642. DOI: 10.1016/j.rser.2017.05.247.

Hasan, M., and Wu, C. (2020). "Estimating energy-related CO_2 emission growth in Bangladesh: The LMDI decomposition method approach," *Energy Strategy Reviews* 32, 100565. DOI: 10.1016/j.esr.2020.100565

Hoekstra, R., and van den Bergh, J. C. J. M. (2003). "Comparing structural decomposition analysis and index," *Energy Economics* 25(1), 39-64. DOI: 10.1016/S0140-9883(02)00059-2

Hou, F. M., Pei, R. T., Liu, C., and Zhang, Y. Z. (2022). "Influences of China's forest product industry embedding in the global value chain on the embodied carbon emissions in trade," *Journal of Central South University of Forestry & Technology* 42(10), 177-188. DOI: 10.14067/j.1673-923x.2022.10.020

Hu, Z. L., and Nie, Y. F. (2020). "The impact of economic globalization on the GVC position: empirical research based on transnational panel data," *International Economics and Trade Research* 36(2), 56-71. DOI: 10.13687/j.gjjmts.2020.02.010

Koilakou, E., Hatzigeorgiou, E., and Bithas, K. (2023). "Carbon and energy intensity of the USA and Germany. A LMDI decomposition approach and decoupling analysis," *Environmental Science and Pollution* 30(5), 12412-12427. DOI: 10.1007/s11356-022-22978-x

Leal, P. H., and Marques, A. C. (2022). "The evolution of the environmental Kuznets curve hypothesis assessment: A literature review under a critical analysis perspective," *Heliyon* 8(11), article e11521.

Li, Z., Mighri, Z., Sarwar, S., and Wei, C. (2021). "Effects of forestry on carbon emissions in China: Evidence from a dynamic spatial Durbin model," *Frontiers in*

Environmental Science 9, article 760675. DOI: 10.3389/fenvs.2022.760675

Li, F., Zhang, Y. Q., and Zhu, X. C. (2021). "Carbon emission calculation of construction machinery during the expressway construction period," *IOP Conf. Ser. Earth. Environ. Sci.* 657, article 12087.

Liu, Y., and Li, L. (2018). "Research on decoupling and its influencing factors of the carbon emission for logistics industry in China," *Environ. Sci. Technol* 41(5),177-181. DOI: 10.19672/j.cnki.1003-6504.2018.05.029

Liu, H. Q., Yan, Q. Y., and Sun, Y. Y. (2011). "Empirical estimation of environmental Kuznets curve of carbon dioxide emissions in China," *Forum on Science and Technology in China* 23(6), 108-113. DOI: 10.13580/j.cnki.fstc.2011.04.019

Liu, X. L., and Wang, Y. L. (2022). "Analysis of driving factors of carbon emissions in China's manufacturing industry based on LMDI decomposition," *Statistics & Decision* 38(12), 60-63. DOI: 10.13546/j.tjyjc.2022.12.011

Liu, T. Z. (2023). *Research on the Factors Influencing Carbon Emissions and Low Carbon Development Path of China's Oil and Gas Industry*. Phd Dissertation, Northeast Petroleum University, Daqing, China.

Liu, Y., and Huang, A. S. (2023). "Characteristics and influence factors of environmental Kuznets curve for forest carbon sequestration," *World Forestry Research* 36(2), 132-137.DOI: 10.13348/j.sjlyyj.2023.0011

Llanos, C., Kristjanpoller, W., Michell, K., and Minutolo, M. C. (2022). "Causal treatment effects in time series: CO_2 emissions and energy consumption effect on GDP," *Energy* 249(3), 82-94. DOI: 10.1016/j.energy.2022.123625

Luo, X. L. (2023). "Research on the development strategies of forestry economy under the dual carbon target," *Shanxi Agricultural Economy* 3, 130-132. DOI: 10.16675/j.cnki.cn14-1065/f.2023.03.040

Man, Y., Li, J. G., Hong, M. N., and Han, Y. L. (2020). "Energy transition for the low-carbon pulp and paper industry in China," *Renewable & Sustainable Energy Reviews* 131, article 109998. DOI: 10.1016/j.rser.2020.109998

Shen, W. H. (2021). *The study on Green Total Factor Productivity of Forest Products Industry in China—Based on the Perspective of Manufacturing Sub-Sectors.* Master's Thesis, Chinese Academy of Forestry Sciences, Beijing, China.

Shen, W. H., W, J. Y., N, Y. L., and Wang, D. J. (2021). "Green total factor productivity of forest products industry in China—Panel data based on 31 sectors of manufacturing industry," *Journal of Northwest Forestry University* 36(4), 282-288. DOI: 10.3969/j.issn.1001-7461.2021.04.40

Tian, H. Z., and Ma, L. (2020). "Study on the change of China's industrial carbon emission intensity from the perspective of sector structure," *Journal of Natural Resources* 35(3), 639-653. DOI: 10.31497/zrzyxb.20200311

Timilsina, G. R., and Shrestha, A. (2009). "Factors affecting transport sector CO_2 emissions growth in Latin American and Caribbean countries: an LMDI decomposition analysis," *International Journal of Energy Research* 33(4), 396-414. DOI: 10.1002/er.1486

Voumik, L. C., Rahman, M. H., and Hossain, M. S. (2022). "Investigating the subsistence of Environmental Kuznets Curve in the midst of economic development, population, and energy consumption in Bangladesh: Imminent of ARDL model," *Heliyon* 8(8), article e10357. DOI: 10.1016/j.heliyon.2022.e10357

Wang, J., and Liu, X. (2016). "Financial inclusion and industrial structure transformation under the new normal of Chinese economy—Analysis based on China's provincial panel data," *Journal of Industrial Technological Economics* 6, 36-42. DOI: 10.3969 /j.issn.1004－910X.2016.06.005

Wang, Q., Zhang, F. Y., and Li, R. (2023). "Revisiting the environmental Kuznets curve hypothesis in 208 counties: The roles of trade openness, human capital, renewable energy and natural resource rent," *Environmental Research* 216(3), article 114637. DOI: 10.1016/j.envres.2022.114637

Xu, J. W. (2013). *Study on the Factors of China's Carbon Dioxide Emissions Based on the LMDI,* Master's Thesis, China University of Mining and Technology, Beijing, China.

Xu, S. M., and Wang L. Q. (2010). "Research review of resources change based on EKC," *World Forestry Research* 23(06), 13-17. DOI: 10.13348/j.sjlyyj.2010.06.009

Xu, S. C., He, Z. X., and Long, R. Y. (2014). "Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI," *Applied Energy* 127, 182-193. DOI: 10.1016/j.apenergy.2014.03.09

Yang, J., Cai, W., Ma, M. D., Li, L., Liu, C. H., Ma, X., Li, L. L., and Chen, X. Z. (2020). "Driving forces of China's CO_2 emissions from energy consumption based on Kaya-LMDI methods," *Science of The Total Environment* 711, article 134569. DOI: 10.1016/j.scitotenv.2019.134569

Yu, T. F., and Xia, E. L. (2021). "Strategies of achieving carbon neutrality in forest products industry in China," *Journal of Forestry and Grassland Policy* 1(3), 10-15. DOI: 10.12344/lczcyj.2021.07.04.0002

Zhang, C. Q., Nie, J. H., and Yan, X. H. (2023). "Estimation of biomass utilization potential in China and the impact on carbon peaking," *Environmental Science Pollution Research* 30, 94255-94275. DOI: 10.1007/s11356-023-28891-1

Zhao, X. M., Zhang, S., and Yuan, C. W. (2021). "Spatial econometric test of China's transportation carbon emissions environmental Kuznets curve," *Statistics & Decision* 37(4), 23-26. DOI: 10.13546/j.tjyjc.2021.04.005

Article submitted: September 12, 2023; Peer review completed: February 11, 2024; Revised version received and accepted: February 18, 2024; Published: April 16, 2024. DOI: 10.15376/biores.19.2.3390-3408