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Research on the path of practical cooperation between China and European Union countries under the environment of carbon neutrality and peak carbon dioxide emissions

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Globalization is increasing daily with the development of the world economy and society. International conflicts, cooperation, and interdependence in international environmental relations have become increasingly prominent, laying a theoretical and practical basis for international environmental cooperation. The ecological protection industries of China and the EU (European Union) are facing great development opportunities. Many EU member states have advantages in developing the environmental protection industry, which facilitates all-around cooperation in the environmental protection industry with my country. Based on the target policy background of PCDE (peak carbon dioxide emissions) and CN (carbon neutrality) and domestic and foreign research, this paper proposes a study on the practical cooperation path between China and EU countries. Based on international input–output data, an economic output CDE (carbon dioxide emission) matrix is constructed to characterize countries' economic and CDE correlation, thus forming a global CDE network. The analysis shows that the contribution rate of energy structure effect and energy intensity fluctuates slowly, indicating a positive and negative alternation; Our government should adopt an active energy optimization policy, speed up the formulation of macro policies such as carbon tax on energy-consuming industries, continuously optimize the energy structure and reduce the CDE intensity. By 2023, China's unit GDP will remain the same by 40–50% compared with 2022. Furthermore, the practical cooperation path proposed in this paper can provide valuable insights for policymakers and stakeholders in both China and the EU to promote the development of the environmental protection industry and achieve the common goal of carbon neutrality. The findings of this study can be used to inform the design and implementation of policies and initiatives aimed at reducing carbon emissions, improving energy efficiency, and promoting sustainable economic growth. Additionally, the international CDE network constructed in this study can serve as a useful tool for monitoring and evaluating the effectiveness of environmental policies and initiatives at the international level. Overall, this paper contributes to the scientific understanding of the complex relationship between economic development and environmental protection and provides practical guidance for promoting international cooperation in the environmental protection industry.

KEYWORDS

carbon neutrality, peak carbon dioxide emissions, carbon emissions, China, EU

1. Introduction

As the largest developing country in the world, climate change poses a severe threat to China's food security, water security, ecological security, energy security, infrastructure security, and people's lives and property security. CDE (carbon dioxide emission) involves all aspects of production and life of human economic activities, including production scale and population, energy structure, industrial structure, technical level, urban and rural structure, and consumption structure (Li et al., 2019, 2020). China's product exports depend heavily on the markets of developed countries such as the EU (European Union), with mechanical and electrical products, raw materials and textile products, miscellaneous products, base metals, and their products accounting for a relatively high proportion. CDE grows at the same time as the economic aggregate. China has become the largest CDE dioxide country in the world. Socialism with Chinese characteristics has entered a new era, and high-quality development has gradually become the main idea of China's development. Electricity sector emission reduction is the key driving factor of CDE decline in European and American countries. Its main driving force is that natural gas and renewable energy replace coal for power generation on a large scale. In this process, market behavior plays a significant role. Therefore, to solve the climate problem, on the one hand, international cooperation is needed. On the other hand, national interests should be considered, and appropriate adjustments should be made. If the actors (sovereign countries) only pursue their interests and do not consider the interests of other actors, competition will arise.

Global warming will not only destroy the whole natural ecosystem but also bring losses to other fields, such as the social economy. Some studies have explored the impact of renewable energy consumption on CDE in BRICS countries. However, the method has yet to fully consider the possible cross-section correlation and heterogeneity in panel data of BRICS countries (Montoya Lupita et al., 2017; Thapa et al., 2017). Because of the slow development of new energy in China, backward clean energy technology, and low energy utilization efficiency, it is particularly urgent to change the coal-dominated energy structure. The contradiction between the economy, energy demand, and environment is becoming increasingly severe, which has become a major issue in front of our country. As a regional international organization with the highest degree of integration in the world today, the EU is the top priority of China's environmental diplomacy (Konemann et al., 2017). In order to seek common interests, China and the EU have taken necessary joint actions and measures to solve environmental problems, and activities on which both sides have had an ordinary impact in the spirit of cooperation and achieved remarkable results. Despite the baptism of the financial crisis and the European debt crisis, the EU's economic foundation is still there, its economic vitality is still strong, investment opportunities and challenges coexist, and it still has a broad prospect of attracting foreign investment.

It must be recognized that PCDE (Peak Carbon Dioxide Emigration) and CN (carbon neutrality) can not only promote the transformation of China's economic structure but also trigger geopolitical changes, thus strengthening the game between big countries (Fernandez et al., 2018). The proposal of China's CN goal has released a positive signal that China will firmly follow the green and low-carbon development path and lead the global ecological civilization and beautiful world construction. Studying the path of pragmatic national cooperation will help us understand the achievements and problems of environmental cooperation between the two sides, find solutions, promote further cooperation between the two sides in the environmental field, and protect the earth on which human beings depend. At the same time, the research on this topic will enrich the theory of international environmental diplomacy and promote the development of this discipline.

2. Related work

2.1. Economic development and CDE-related research

Environmental Kuznets Curve (EKC) means an inverted U-shaped relationship between economic growth and CDE. In the initial stage of economic development, CDE increases with economic growth, but when economic development reaches a certain threshold, CDE is inversely proportional to economic development. Many scholars have tested the applicability of this theory in various countries.

Qin et al. (2019) pointed out that the EKC hypothesis did not fully consider the two-way influence between economic growth and CDE and only included the one-way influence of economic development on CDE in the model, which led to endogenous problems in the model and used traditional Granger test to test the causality between economic development and CDE. Clarke et al. (2017) applied the global vector autoregressive method to incorporate the two-way relationship between economic growth and CDE into the model, focusing on the dynamic impact of China's economic growth on international CDE and major economies. Shi and Lee (2017) considered the transmission path of the dynamic relationship between economic growth and CDE under different openness. The results showed that expanding China's trade openness would increase its CDE, aligning with China's pollution paradise hypothesis (Shi and Lee, 2017).

McGrath and Liam (2017) comprehensively analyzed the characteristics of cargo arrival time, carbon dioxide emission, and line reconstruction ability. They set up an optimization model of long and significant cargo multimodal transport path expansion (McGrath and Liam, 2017) to minimize cost and CDE amount. Cosmas et al. (2019) explored the influence of four factors, such as energy consumption in BRICS countries, on CDE and found that increasing renewable energy consumption is conducive to carbon emission reduction (Cosmas et al., 2019). Naminse and Zhuang (2018) think that the service industry is immaterial and knowledge-intensive, so the shift of economic structure to the service industry is conducive to carbon emission reduction. Hao and Huang (2018) established multivariate economic growth models such as capital, labor, and energy consumption. They selected data on energy consumption and economic output to make a panel analysis of the relationship between energy consumption and economic growth in 16 Asian countries (Hao and Huang, 2018).

2.2. Research on panel data analysis method

The research on the impact of energy economic structure is mainly based on long-term and short-term panel data analysis, and the analysis of non-stationary panel data is more common. The appropriate panel data analysis methods are constantly developing and improving.

Takeuchi et al. (2021) think that due to some differences in economic data of different countries, heterogeneity should be fully considered in the research, and the panel method that allows heterogeneity to exist is used to explore the relationship among global energy consumption, economic growth, foreign direct investment, and financial development. Yu et al. (2018) used the traditional estimation method based on the assumption of cross-section independence, and the research results obtained will be biased.

Xiao-Jun et al. (2018) took the three factors of transportation cost, transportation time, and total CDE in transportation activities as the main influencing factors of multimodal transport route optimization. They established a Sino-European container multimodal transport route optimization model (Xiao-Jun et al., 2018). The manufacturing industry is divided into the low-carbon manufacturing industry and the high-carbon manufacturing industry. The research of Li and Bell (2017) shows that carbon leakage mainly occurs in the high-carbon manufacturing industry. At the same time, there is no carbon leakage problem in the manufacturing and low-carbon manufacturing industries (Li and Bell, 2017). Cheng et al. (2017) proposed a network optimization model of multimodal transport based on the principle of objective programming and can handle multi-objective and conflicting objective functions. Sensitivity analysis explores several non-dominant transport situations and analyzes potential competitiveness (Cheng et al., 2017). Qiu et al. (2017) think that if active measures such as industrial structure adjustment, technological progress, and emission reduction policies are taken simultaneously, the peak time can be advanced to 2026. Achieving carbon neutral requires a comprehensive understanding of the effect of different key factors on carbon emissions. To this end, this study investigates the effect of trade openness, human capital, renewable energy and natural resource rent on carbon emissions within the framework of the environmental Kuznets curve (EKC) hypothesis (Wang et al., 2023b). The traditional environmental Kuznets curve (EKC) hypothesis explains the inverted U-shaped relationship between the economy and the environment. This study expands the traditional EKC theory by adding social indicator, which also corresponds to the three aspects (social, economic, and environmental) required for sustainable development in 2030 (Wang et al., 2022). At the sub-regional level, trade openness favors carbon neutrality in rich countries, but not in poor countries. Thus, achieving carbon neutrality requires free trade, and fairer free trade needs to benefit countries of different income groups (Wang et al., 2023a).

3. Research method

3.1. Characteristic analysis of international CDE network

The realization of PCDE and CN is the inherent requirement of building a beautiful China where man and nature coexist harmoniously and promote high-quality development. It should be pushed forward unswervingly, but it is only possible to accomplish some of the work in one battle. It should be done simultaneously and steadily. The Paris Agreement will officially enter the implementation period after 2020, and the global green and low-carbon transformation will be significantly accelerated. The economic and social development and international trade and investment will undergo significant changes in the future, which is an improvement and a change. When the economic growth rate is moderately slowed, China will achieve the maximum CDE by 2035. After the realization of PCDE, China entered the CN period. At present, some domestic scholars have put forward suggestions on the realization path of CN from different angles, such as production mode and industrial sector, to help achieve the goal of CN as soon as possible.

However, the principles of common but differentiated responsibilities, fairness, and respective capabilities are the basic principles that global climate governance should follow. Due to the different industrial stages and division of labor, China exports many high-carbon products to the EU, leaving greenhouse gas and pollutant emissions at home, becoming a "pollution refuge" for developed countries. Even if the EU gives the default value of the carbon content of products, the differences in production processes and raw materials in different countries will make the default values different, which cannot cover the same kind of goods in all countries (Zheng et al., 2021). The EU still needs to clarify whether to consider the hidden carbon price brought by policies such as standards or regulations. Even considering the hidden carbon price, how quantifying the carbon emission reduction cost of such policies is a technical problem to be solved in the future.

China and the EU have gradually formed various cooperation mechanisms in continuous cooperation. All kinds of cooperation mechanisms have gradually played an enormous role in continuous improvement and have built a good cooperation platform between the two sides in the environmental field. In order to guide and coordinate the implementation of the cooperation plan, sum up the achievements, exchange experiences and adjust the plans and actions of the project in time, a steering committee of the China-EU cooperation plan on environmental management, jointly headed by the Ministry of Commerce and the European Mission in China, has been set up, which is of positive significance to the development of the plan.

When binarizing the international CDE matrix, the critical step is to select the threshold value, keep the carbon transfer links higher than the threshold value in the matrix, and remove the carbon transfer links lower than the threshold value. For example, with the increasingly close production relations and economic ties among countries, the network density reflecting the integrity of the international CDE matrix should gradually increase. The relative position of the matrix density each year will change slightly for different threshold values. In the binary international CDE network, enough connections are kept, and weak CDE connections are omitted, which is convenient for analyzing the prominent structural characteristics of the CDE network.

According to the CDE C_j, consumption standard quantity e_j and consumption structure proportion s_j of the j energy caused by fossil energy combustion, it is calculated as follows:

$$C_j = AD_j \times N_j. \tag{1}$$

$$e_j = AD_j \times P_j. \tag{2}$$

$$s_j = \frac{e_j}{\sum_j e_j}. \tag{3}$$

where: AD_j represents the physical quantity of the j -th energy consumption; N_j represents the CDE coefficient of the j th energy source; P_j is the discounted coal coefficient of the j energy source.

PCDE and CN goals effectively empower China's ecological civilization construction and comprehensively promote upgrading social cognition to a green and low-carbon perspective, reflecting the first enabling form of dual-carbon goals. At the same time, this development path harms the realization of PCDE and CN in China. Reducing pollution and improving environmental quality is one of the goals of PCDE and CN. Double carbon targets can effectively enhance the vitality of enterprises, enhance the technical level, and effectively promote the implementation of China's innovation-driven strategy. See Figure 1 for the internal logic of PCDE and CN, enabling high-quality development.

The innovation of CDE and CN is reflected in the following aspects:

(1) The introduction of dual carbon targets: The introduction of carbon peaking and carbon neutrality as targets for enterprise development was pioneered by China on a global scale. The achievement of this goal not only helps reduce greenhouse gas emissions and protect the global environment but also promotes the transformation and upgrading of enterprises to a green and low-carbon direction, enhancing their competitiveness and sustainable development.

(2) Comprehensively promote the upgrade of social cognition to a green and low-carbon perspective: The launch of CDE and CN is not only the goal of enterprise development but also a sign of upgrading social awareness. Through publicity and education, more people can be made aware of the importance of environmental protection and carbon emission reduction, thus forming a good atmosphere for the whole society to promote the construction of ecological civilization jointly.

(3) Promote the implementation of the innovation-driven strategy: Realizing the dual carbon goal requires enterprises to innovate, improve technology, and promote industrial upgrading continuously. This coincides with the innovation-driven strategy proposed by China, which can effectively promote the implementation of this strategy and the high-quality development of China's economy.

In conclusion, the innovation of CDE and CN lies in introducing the dual carbon target into enterprise development, promoting social cognition to upgrade to the green and low-carbon direction, facilitating the implementation of the innovation-driven strategy, and injecting new momentum into the construction of ecological civilization and sustainable economic development in China.

The application and diffusion of emission reduction and carbon control technology in China can also break the western technology blockade and achieve technological independence. At the same time, as a world economic power, the improvement of China's energy structure will help to improve the world's energy structure, gradually reduce the world's dependence on oil and gas resources, and promote the world's energy consumption revolution. The realization of PCDE and CN goals will help to show China's role as a big country, improve China's international status, strengthen China's right to speak in the international community, break the blockade of political, economic, and moral public opinion in western countries, and also help China's strategic communication with other economies, to truly achieve all-round and high-quality development based on the double-cycle new development pattern.

We can achieve high-quality energy development through energy conservation and efficiency improvement, energy structure optimization, and technological innovation (Xiao-Jun et al., 2018). Regarding import and export, China needs to work with other economies to maintain the ecological environment and promote the global development of low-carbon life. The country must formulate a strict import and export supervision system to ensure the low-carbon and environmental protection of imported and exported products. We can appropriately introduce high-end foreign talents to strengthen the innovation vitality, jointly devote ourselves to the research and development of low-carbon environmental protection technologies, promote the low-carbon development of the industrial chain, and lay a sound technical foundation for PCDE and CN.

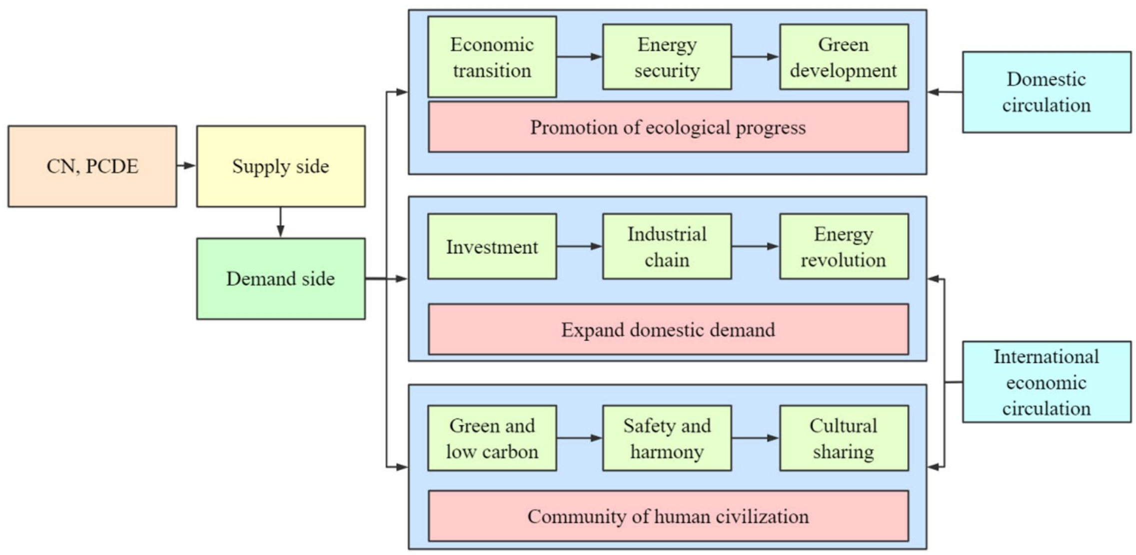

FIGURE 1
Peak carbon dioxide emissions (PCDE) and CN empower the internal logic of high-quality development.

Furthermore, product and energy service demand constraint means that for a given industrial product or transportation and construction service, the product of all equipment operation quantity and unit equipment product or service output quantity must be greater than or equal to the demand of the product or service, thus reflecting the actual process of fixed production according to demand. The expression is:

$$\sum_{d}^{D} OT_{i,d,j,t} \cdot OQ_{i,d,j,t} \cdot \left(1 - EFF_{i,d,j,t}\right) \geq DS_{i,j,t}. \tag{4}$$

Among them, $OT_{i,d,j,t}$ ——The unit output of equipment d in industry i producing products or energy services j in year t;

$OQ_{i,d,j,t}$ ——Operation number of equipment d for producing products or energy services j in industry i in year t;

$EFF_{i,d,j,t}$ ——The technological progress rate of equipment d in industry i producing products or energy services j in year t;

$DS_{i,j,t}$ ——Total demand of products or energy services j of industry i in the t year.

Network density is an index that reflects the density of carbon transfer relationships among countries in the international CDE network, and reflects the overall characteristics of the network. The more relationships among countries in the CDE network, the greater the network density. It is defined as the ratio of the actual number of carbon connections between countries to the maximum number of carbon connections possible in the whole network. The network density D_{nt} of the international CDE matrix in the t year is:

$$D_{nt} = \frac{\sum_i \sum_j d_{ijt}}{n(n-1)}, 0 \leq D_{nt} \leq 1, i \neq j. \tag{5}$$

Among them, n is the number of countries in the international CDE network, $\sum_i \sum_j d_{ijt}$ is the actual number of carbon associations in the network in the t year, and $n(n-1)$ is the most possible number of carbon associations in the network.

From the perspective of cost–benefit, any calculation of carbon tax rate should be equal to the marginal loss of global warming, that is, at a certain point, the marginal loss is equal to the marginal control cost. In addition, if benefit evaluation is not pursued, the tax rate should be equal to the marginal control cost aiming at emission reduction.

Therefore, the carbon tax rate is calculated as follows:

$$C_e = \sum_{0}^{t} D_t (1 + \lambda)^{-1}. \tag{6}$$

Formula C_e represents carbon tax; D_t represents the damage value in the t year caused by a ton of CDE, and λ represents the discount rate.

3.2. Carbon density and energy structure

It supports the national economy but is also the primary source of environmental pollution. The traditional industries with high pollution and energy consumption urgently need to adjust the industrial structure, reduce energy consumption and emissions, carry out cleaner production, and move towards the sunrise. Produce food beneficial to human health, and realize the sustainable development of agriculture to protect the soil structure and ecological balance. Consumers' awareness of health has increased, and they are willing to buy environmentally friendly products, such as fluorine-free refrigerators and phosphorus-free laundry detergent, especially children's products. The sales volume of green and pollution-free environmentally friendly products is better than that of ordinary children's products. Suppose our products want to enhance international competitiveness. In that case, we must take the development of the environmental protection industry as the premise, take environmental protection technology as the support, get rid of the traditional situation of high energy consumption, high emissions, high pollution, low labor cost, and export of primary products, and increase the export of green products and environmental protection products.

Establishing a long-term, stable, equal partnership between China and the EU is conducive to world peace and development. The development of China-EU environmental cooperation can complement each other's advantages, positively promoting the China-EU partnership. The scope of application has also expanded rapidly, from domestic environmental problems to global environmental problems. EU has rich experience in environmental tax, investment and financing, environmental funds, and ecological tax reform. Cleaner production has been mainly implemented by supply strategy in the world in the past 10 years. In recent years, the research on establishing a demand implementation model with the government as the propeller, enterprises as the main body, and the market as the guide has been intensified. The cooperation between China and Europe in the environment and sustainable development field will be further developed, and win-win results will be achieved. The prospect of cooperation is comprehensive.

Carbon density is the ratio of carbon dioxide emissions to energy consumption. Therefore, carbon density can reflect the energy consumption structure of the industry. Because different energy sources release different carbon dioxide while providing energy, on the one hand, the demand for rising energy prices will decrease correspondingly, and the prices of energy-intensive products will rise correspondingly, and the energy intensity will decrease accordingly. On the other hand, energy becomes more expensive compared with other factors of production, and producers will choose to improve production technology to reduce energy consumption, leading to a decline in energy intensity. The fierce competition has also become the pressure of technological advancement of enterprises. Low-level expansion and other issues. These industries can make good profits only by relying on traditional technology. This caused a lack of motivation and motivation for technological advancement in enterprises during this period.

The circular economy is essentially an ecological economy, which is the concrete embodiment and realization way of the concept of sustainable development. It requires following ecological and economic laws, rationalizing natural resources and environmental capacity, and developing the economy on the principle of "reduction, reuse and recycling." Developing a low-carbon economy will vigorously promote the development of low-carbon energy. Modern transportation fuels such as gasoline and diesel and crucial primary chemical products such as olefins and aromatics all use petroleum as their primary raw materials. The dependence of human economic activities on petroleum has formed the so-called petroleum economic model. The framework of the low-carbon economic development model is shown in Figure 2.

Reconstruct the economic system according to the law of material circulation and energy flow in the natural ecosystem so that the economic system can be harmoniously incorporated into the material circulation process of the natural ecosystem and realize the colocalization of economic activities to establish an ecological socio-economic system in harmony with the structure and function of the ecological environment system. This spiral structure contains four spirochetes, namely financial institution spirochetes, government spirochetes, scientific research institutions spirochetes, and enterprise spirochetes. The common interests of these spirochetes can promote the improvement of the carbon financial system, realize the "linkage effect" between carbon finance and a low-carbon economy, and then promote the development of the low-carbon economy.

In this paper, based on EKC theory modeling, in order to ensure the robustness of the estimation results, the *per capita* GDP and its square term are selected as independent variables and CDE as dependent variables, and the basic model is established as shown in formula (7):

$$\ln\left(TC_{it}\right) = a_0 + a_1 \ln\left(GDP_{it}\right) + a_2\left[\ln\left(GDP_{it}\right)\right]^2 + \varepsilon_{it}. \quad (7)$$

where i represents EU countries, and t represents the number of years included in the sample interval. $\ln(TC), \ln(GDP)$ measure CDE and economic growth, respectively. a_0 is a constant term, a_1, a_2 is the regression coefficient of $\ln(GDP)$ and its square term respectively, and ε_{it} is a random error term.

China's energy intensity, the amount of energy consumed per unit GDP, is decreasing, but there is still a big gap with the world average. Given China's current economic development and energy consumption, the situation of energy conservation and emission reduction in China could be more optimistic. It is necessary to mobilize the whole society to make joint efforts. Kaya identity is widely used in the research of CDE, and it is a well-recognized and commonly used method in current academic circles. Kaya identity decomposes CDE quantity into various driving factors, which can be expressed explicitly as:

$$CO_2 = \frac{CO_2}{EN} \times \frac{EN}{GDP} \times \frac{GDP}{POP} \times POP = C \times E \times P. \quad (8)$$

CO_2 represents CDE, EN represents primary energy consumption, GDP represents gross domestic product, and POP represents the total population in China. Correspondingly, C stands for "energy structure effect" and E stands for "energy intensity," that is, the amount of energy consumed per unit GDP; Y represents economic factors, and P represents population factors, that is, the total population.

In addition, this study defines φ_i as the total damage function of greenhouse gas emissions in country 1. The total greenhouse gas emission damage function of the importing country is the sum of the cross-border emission damage $m_{10}q_1$ caused by the exporter 1 and the cross-border emission damage $m_{20}q_2$ caused by the exporter 2, as shown in the following formula:

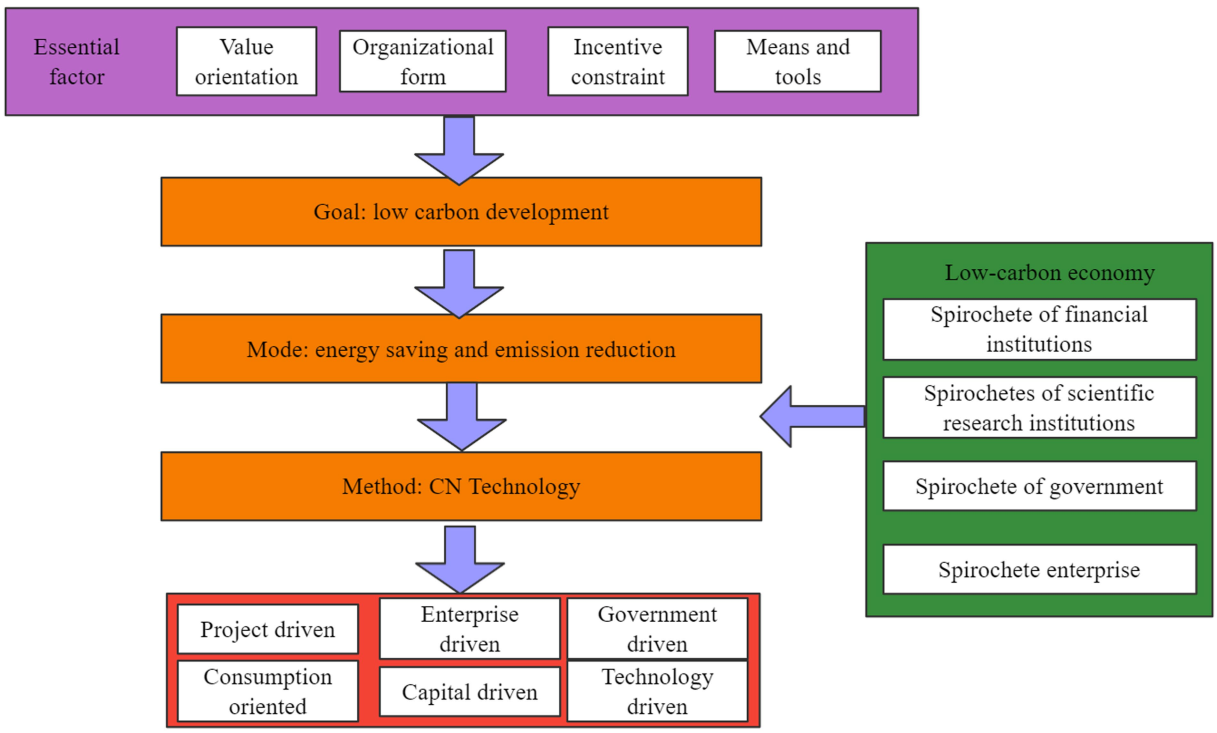

FIGURE 2
Low-carbon economic development model framework.

$$\varphi_0 = m_{10}q_1 + m_{20}q_2. \tag{9}$$

The total damage function of greenhouse gas emissions from exporting country 1 is the regional emission damage $m_{11}q_1$ from exporting country 1 and the transboundary emission damage $m_{21}q_2$ from exporting country 2 to exporting country 1, as shown in the following formula:

$$\varphi_0 = m_{11}q_1 + m_{21}q_2. \tag{10}$$

The above formula shows that the optimal tariff rate levied by the importing country on the two exporters is positive, because the importing country guides the two exporters to tax the transboundary emissions emitted by the importing country. It also means that the effect of increasing tariff revenue and reducing environmental greenhouse gas emission damage is greater than that of decreasing consumer surplus. Therefore, the importing country guides two foreign exporters to levy import tariffs.

4. Result analysis

Energy intensity directly reflects the utilization rate of energy and the efficiency of production. Generally speaking, developed countries improve energy utilization and output through technological progress and innovation. The energy intensity is low; *Per capita* GDP reflects a country's average living standard and macroeconomic situation. On the one hand, the economy needs energy consumption to promote it; on the other hand, economic development drives technological innovation and progress, contributing to the research and development of clean energy and improving production technology. Especially with the acceleration of urbanization, the increase in urban population will increase CDE by increasing energy consumption.

In this paper, the data from 2000 to 2021 are selected and decomposed according to the formula, and each driving factor's contribution value and contribution rate to CDE variation are obtained. The calculation results are shown in Figures 3, 4.

As seen in Figure 3, in the past 20 years, economic factors have played a positive role in promoting the change of CDE, which is significantly greater than other factors. Population factors have also played a positive role in promoting the change of CDE. However, the effect is far less than that of economic factors and is balanced, with little change in value. Nevertheless, generally speaking, the energy structure effect plays a positive role, and energy intensity plays a role in reducing emissions. Economic prosperity needs to be driven by energy, and improving people's material living standards also increases the demand for energy consumption. Economic factors always positively impact the increase of CDE changes.

As can be seen from Figure 4, on the whole, the fluctuation of the driving contribution rate of energy structure effect and energy intensity to CDE change is relatively consistent, with a sizeable annual fluctuation, and the fluctuation tends to be stable since 2003. The energy structure effect and intensity both decrease and when the total amount of CDE increases, the energy structure effect, and energy intensity inhibit it. From 2001 to 2009, the contribution rate of energy structure effect and energy intensity fluctuated slowly, showing a

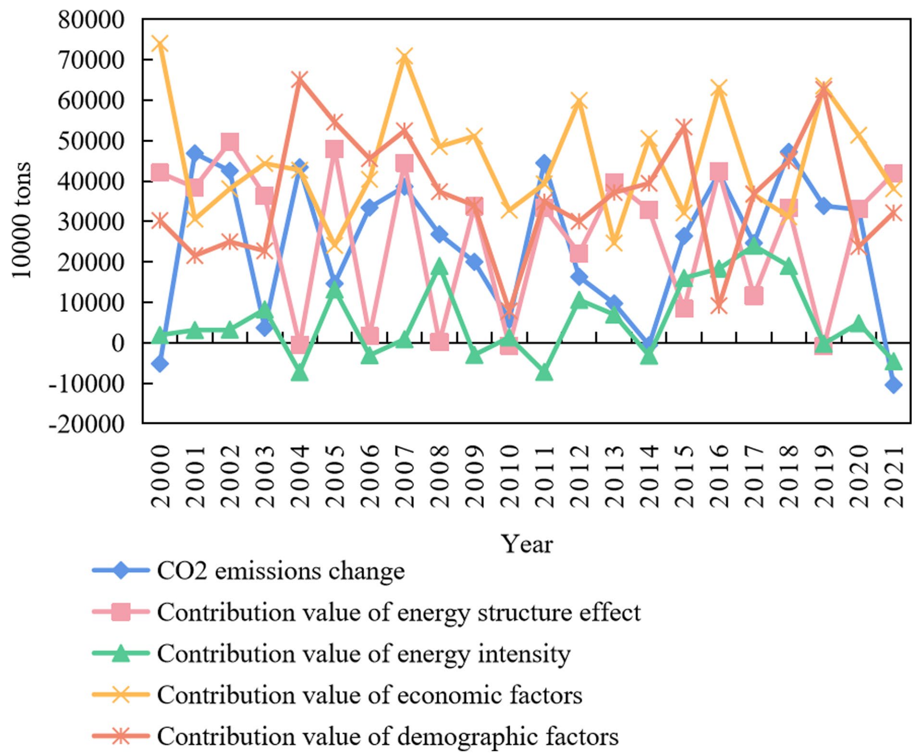

FIGURE 3
Carbon dioxide emission (CDE) driver decomposition results.

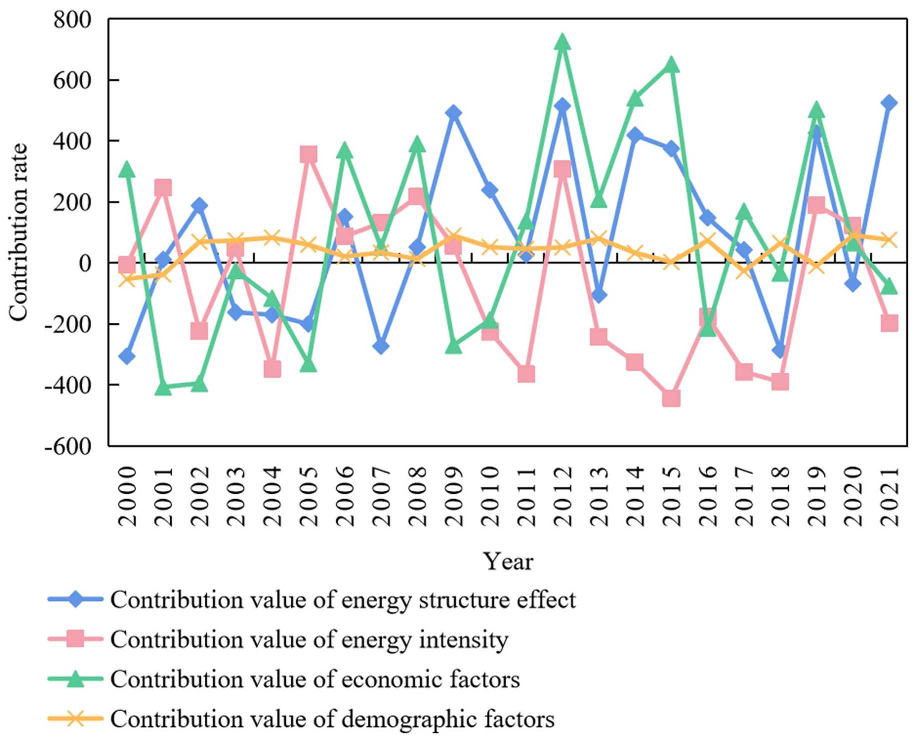

FIGURE 4
Contribution rate of CDE change.

TABLE 1 Annual GDP growth forecast.

Stage	Low speed	Intermediate speed	High-speed
2021—2025	3.74	2.22	4.91
2026—2030	1.94	2.54	4.36
2031—2035	3.9	5.73	4.97
2036—2040	3.6	5.54	5.27
2041—2050	2.74	3.05	5.05
2051—2060	2.13	5.16	4.98

positive and negative alternation. The increase in CDE showed that the driving effect of these two factors on CDE also changed positively and negatively.

Economic factors, energy structure effect, and energy intensity have a changing trend of offsetting each other, especially in the year when the extreme value appears, so the contribution rate of economic factors, energy structure effect, and energy intensity always show a reverse changing law. Generally speaking, the positive driving effect of CDE change of population factor is small, and with the change of time, this positive driving effect is still weakening.

The factors and processes each industry considers in forecasting the demand for products or services are quite different. Therefore, here, only each industry's standard parameters of demand forecasting are explained. The future economic growth rate of China is shown in Table 1.

With the continuous development of the manufacturing industry, independent design, R&D capability, and manufacturing level have been continuously improved, and large quantities of high-quality products have been delivered to the retail industry, which improves the position of the global value chain. Retail products are more competitive in the international market. With the increase in the ratio of capital to labor remuneration, more capital is used in low-end links but not in high-end links, such as improving production efficiency and saving energy, which will still promote the growth of CDE. Therefore, at this stage, upgrading the technical level of the retail industry is only an attempt to improve the convenience of the retail industry. However, it cannot be matched with the energy conservation and emission reduction goal in a short time. To achieve the goal of energy conservation and emission reduction, the retail industry needs to adopt more sustainable practices. This can involve various measures, such as reducing packaging waste, promoting the use of reusable bags, and implementing energy-efficient lighting and heating systems in stores. Additionally, the retail industry can explore the use of eco-friendly materials and products in their operations, which can help reduce their overall carbon footprint (Yuan et al., 2022). However, these measures may require significant investments and changes in business practices, which may not be immediately feasible for all retailers. In this regard, government policies and incentives can play a crucial role in encouraging the adoption of sustainable practices in the retail industry. For example, tax incentives can be provided to retailers who adopt energy-efficient practices, and regulations can be implemented to encourage the use of sustainable materials and products (Li et al., 2022; Naqvi et al., 2022).

TABLE 2 Conversion coefficient of CDE quantity.

Energy category	CDE coefficient (kg/GJ)	Standard coal conversion coefficient	Calorific value (kj/kg)	Oxidation rate (%)
Coal	3	0.3	23,031	0.95
Petroleum	3	0.23	21,368	0.91
Natural gas	19	1.32	11,107	0.92
Petroleum products	13	0.48	5,081	0.92
Coke	15	1.34	10,472	0.97
Power	8	1.55	18,415	-
Fuel gas	8	1.17	4,950	0.95

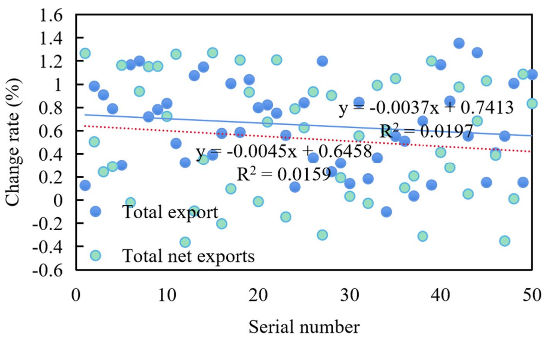

FIGURE 5
Changes of China's exports by industry under the carbon tariff rate of $100.

In the model, carbon tariff is the cost of export products and is included in the price of export products. This paper also assumes that the world price is constant and fixed, and individual countries will not affect it. When the world price is fixed, the increase in the cost of export means that some profits of products are obtained abroad. The calculation of the unit CDE quantity of a product needs to convert all kinds of energy necessary for the production of a product into standard coal consumption by converting it into standard coal coefficient and then calculate the CDE quantity in the production of a product by using calorific value, CDE, oxidation rate and other coefficients. Specific values are shown in Table 2.

The most direct impact of carbon tariffs is the restriction on export profits. Foreign countries have plundered many carbon tariffs from China's foreign trade by levying carbon tariffs. With the continuous improvement of carbon tariffs, foreign countries' total amount of carbon tariffs levied constantly increases. The profits lost in China's foreign trade will also be transferred like those of developed countries. As a result, China's exports have shrunk, resulting in huge losses.

After foreign countries' imposition of carbon tariffs, China's exports and trade surplus have been adversely affected. China's exports have been greatly affected by the continuous increase of carbon tariffs. This is because, after the reduction of export prices, the profit per unit product of China's exports has also decreased, resulting in the shrinking of exports. Then the sharp drop in total exports has led to the continuous decline of trade surplus.

Among the trade with EU countries, China's exports to the United States are most affected by carbon tariffs, with the most significant drop in export value. In contrast, its exports to other countries are less affected. The impact of carbon tariffs on China's exports of various industries is shown in Figure 5 below.

The results show that carbon tariff significantly influences China's exports, including the fuel processing industry; Coal mining and washing industry; Metal products industry; Printing industry, manufacturing of cultural and educational articles; Textile industry; Cement, lime, and gypsum manufacturing industries, etc. Therefore, our government should adopt active energy optimization policies, speed up the formulation of macro policies such as carbon tax on energy-consuming industries, continuously optimize energy structure and reduce CDE intensity.

In this paper, China's real GDP is positively impacted by a standard deviation, and the response function values of CDE quantity of four representative economies are obtained. The results are shown in Figure 6.

The impact of China's economic growth on some emerging economies in the EU also presents an inverted U-shaped trend. However, the impulse response function of the two countries is always greater than zero, which does not show the characteristics of positive and negative alternation of CDE growth. China's economic growth has achieved complementary advantages and positive interaction with the economical production of some emerging economies, prompting the increase of CDE.

In addition, due to China's economic growth, CDEs of nine representative economies have differences in response size and response time lag. The EU CDE impulse response function's fluctuation amplitude and response speed are the most prominent. China is at the middle level of the global value chain, while the EU is at the high end of the global value chain. The impact of China's economic output is conducted from bottom to top along the global value chain channel, resulting in apparent fluctuations of EU CDE.

According to the above settings for each factor, we predict the growth rate of each factor. From the predicted data, it can be seen that the change in carbon density in China by 2023 is not very obvious. However, the energy density change is significant, showing that China's technical level has improved. Figure 7 shows the CDE prediction results in four scenarios.

The analysis results predicted by Scenario 3 and Scenario 4 cannot reach the emission reduction target of 40% to −50% of China's unit GDP in 2023 compared with 2022. In the next 10 years, China will still be under heavy industrialization.

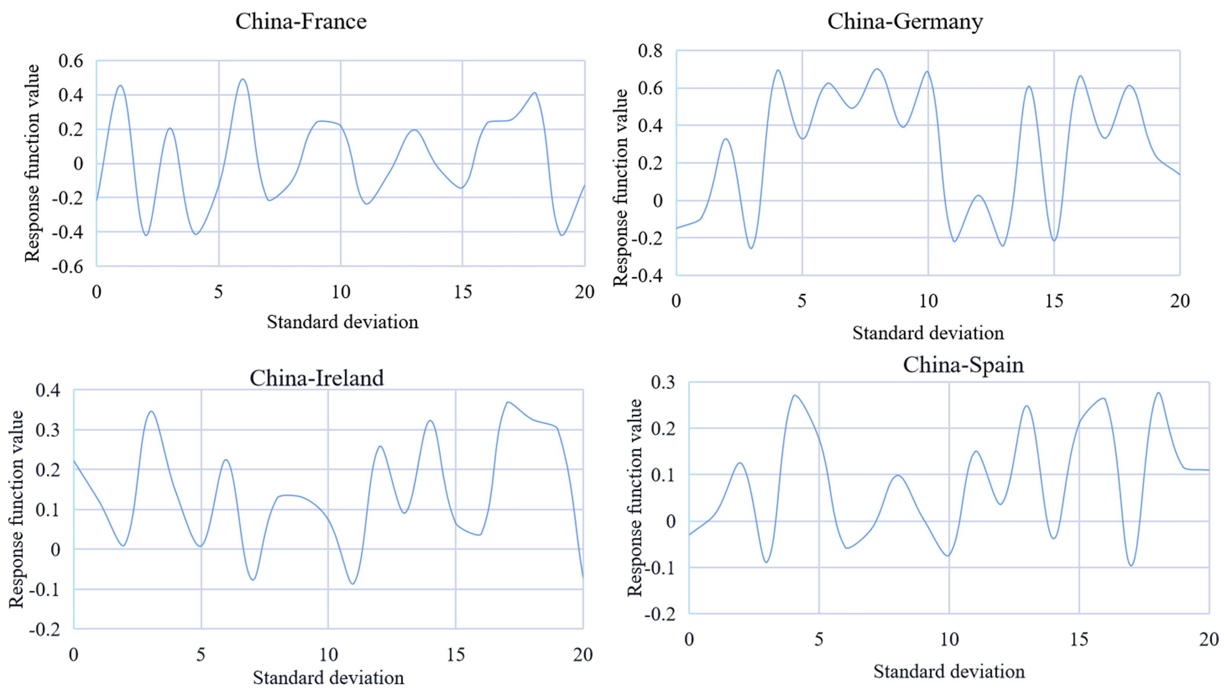

FIGURE 6
The influence of China's economic growth on CDE, a representative economy.

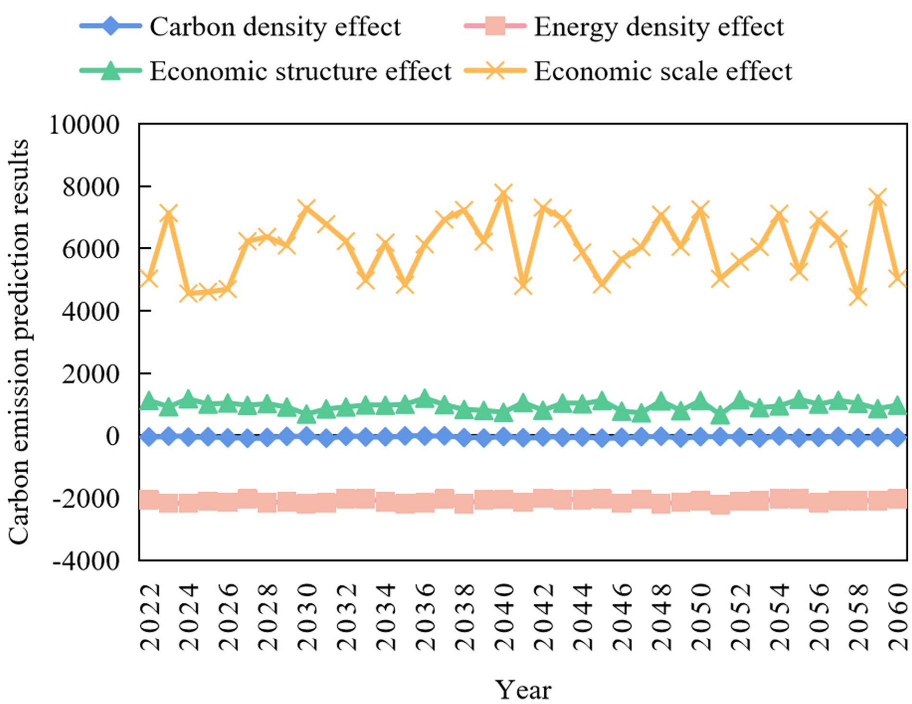

FIGURE 7
Carbon dioxide emission prediction results.

However, if the industrial sector develops at a growth rate of 7%, China will not be able to achieve the emission reduction target by 2023. It shows that China has dramatically improved its technical level and economic structure adjustment while developing its economy, which has played a role in curbing carbon dioxide emissions. However, the effect of carbon density is minimal, which shows that there is still much room for China to improve its energy structure.

5. Conclusion

Developing the environmental protection industry under the environment of PCDE is the general trend, and cooperation between China and the EU environmental protection industry is the inevitable choice. This paper concludes the pragmatic cooperation path between China and EU countries using relevant economic theory, EKC theory, and Kaya model analysis. After research, the specific conclusions of this paper are as follows: Economic factors always have a positive impact on the increase of CDE changes. The positive driving effect of CDE change of population factor is small, and with the change of time, this positive driving effect is still weakening. Among the trade with EU countries, China's exports to the United States are most affected by carbon tariffs, with the most significant drop in export value. In contrast, its exports to other countries are less affected. The predicted analysis results cannot reach the emission reduction target of a 40–50% reduction of China's unit GDP compared with 2022 by 2023.

The main contribution of this study is to propose a new pathway for achieving dual carbon goals-CDE and CN goals, which has achieved effective promotion in the construction of ecological civilization in China. Our findings show that CDE and CN goals can effectively promote technological innovation and transformation and upgrading of enterprises and effectively promote the upgrading of social cognition to a green and low-carbon perspective. In addition, our study reveals the limitations of PCDE and CN realization in China, which is an essential guideline for future dual carbon goal realization.

Our findings have a solid practical and replication value. Our results can provide references and insights for other countries and regions to achieve the dual carbon goal. In addition, our findings also provide necessary theoretical and practical support for the construction of ecological civilization and green low-carbon transition in China.

Of course, our research results also have certain limitations. Our study only focuses on the situation in China, and further research may be needed for the practice in other countries and regions. In addition, our findings need further empirical studies to verify their effectiveness and feasibility.

Future research directions can be carried out in the following aspects: first, the paths and mechanisms for achieving the dual carbon targets can be further studied in depth to explore practice models that are more suitable for different countries and regions; second, the synergistic mechanisms for achieving the dual carbon targets can be explored from the perspectives of enterprises and governments to promote the green and low-carbon transition further; finally, the evaluation and monitoring of the achievement of the dual carbon targets can be strengthened to provide Finally, the assessment and monitoring of the triumph of double carbon targets can be supported to provide more scientific guidance for practice.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

WC was responsible for designing the framework of the entire manuscript from topic selection to solution to experimental verification.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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