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Original Research

Study on Measurement and Driving Factors of Carbon Emission Intensity From Energy Consumption in China

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Abstract

In order to explore effective ways to reduce carbon emission intensity from energy consumption in China, on the basis of literature review and current situation analysis, the method of combining the energy chemical structure and combustion carbon emission principle was adopted, making a scientific measurement of carbon emission and its intensity from energy consumption in this paper. Firstly, the change law of China's carbon emission intensity from energy consumption was analyzed according to the measurement results. Secondly, through the systematic analysis of Kaya method, with full consideration to the actual situation of carbon emission from energy consumption in China, Kaya model was revised by choosing the following factors as independent variables: per capita CO_2 emission (*PC*), per capita energy consumption (*PE*), energy consumption intensity of environmental pollution treatment investment (*QI*), the proportion of environmental pollution treatment investment to GDP (*IG*), etc. On this basis, the empirical test model was constructed for the driving factors of carbon emission intensity from energy consumption in China, and the empirical equilibrium equation and the error correction equation were determined through stability test, lag order test and co-integration test. The results show that all factors have a positive effect on carbon emission intensity from energy consumption, with influence elasticity of 0.8913, 0.9854, 1.0078 and 1.0169. Among all driving factors, *IG* has the greatest influence degree, followed by *QI*, the reciprocal of *PE* (PE^{-1}) and the *PC*. Our research results are of great significance to help the government formulate effective carbon emission intensity control policies and promote the realization of the "double carbon" goal.

Keywords: carbon emission intensity, energy consumption intensity, energy consumption, measurement methods, driving factors

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Introduction

With the rapid development of China's social economy, especially the acceleration of urbanization, the scale of energy consumption is also increasing greatly. The national energy consumption increased from 1.4696 billion tons of standard coal in 2000 to 4.980 billion tons in 2020, with a growth rate of 238.87% and an average annual growth rate of 11.94%. The CO_2 emission from energy consumption (hereinafter referred to as "carbon emission") increased from 3.328 billion tons in 2000 to 12.565 billion tons in 2020, with a growth rate of 277.55%; the carbon emission intensity from energy consumption decreased from 3.319 tons/ten thousand yuan in 2000 to 1.237 tons/ten thousand yuan in 2020. According to the statistics of the World Environment Organization, China's CO_2 emission from energy consumption reached 9.441 billion tons in 2015, with per capita emissions reaching 6.87 tons and rising to 7.0136 tons per capita in 2016, making China the world's largest CO_2 emitter. To this end, the Chinese government pledged to reduce CO_2 emission intensity by 40-50% by 2020 compared to 2005 and by 50-60% by 2030 at the United Nations Climate Change conference in Copenhagen. In September 2020, the Chinese government proposed to "aim to have CO_2 emissions peak by 2030 and achieve carbon neutrality by 2060" at the 75th UN General Assembly, which is referred to as the "double carbon" goal. The carbon emission intensity from energy consumption in China has already been greatly reduced, but there is still a big gap with the United States whose carbon emission intensity from energy consumption is below 0.5 tons/ten thousand yuan. In 2020, China's actual per capita carbon emission is 8.9 (tons/person), which is 26.90% higher than that of 7.0136 (tons/person) in 2016. In this case, it is particularly important and urgent to study the measurement of carbon emission intensity from energy consumption in China and analyze main driving factors of carbon emission intensity from energy consumption using empirical study methods, so as to provide management tools for energy saving and emission reduction for enterprises and a basis for local governments to formulate energy saving and emission reduction policies [1].

The research on energy consumption and carbon emission intensity and its impact has been conducted relatively early in developed countries. Samouilidis and Mitropoulos studied the relationship between energy consumption and economic growth in industrialized countries by taking Greece as an example, and believed that energy consumption was the driving force of economic growth, but that it also caused serious environmental pollution [2]; Torvanger first used the Kaya method to estimate CO_2 emission of manufacturing industries in 9 countries of the Organization for Economic Cooperation and Development [3]; Shrestha and Imilsina studied the driving factors of CO_2 emission intensity in Asian power industry by using the Kaya method [4]; Nag and Parikh studied the calculation method of carbon emission intensity index in the process of India's commercial energy use and the specific countermeasures of emission reduction [5]; Ang and Liu studied global overall energy consumption and made a transnational analysis on the carbon emission intensity from energy consumption [6]; Lotfalipour et al. analyzed the relationship between Iran's economic growth, CO_2 emission and fossil fuel consumption, and considered that fossil fuel consumption was the driving force of economic growth and the main source of serious carbon emission in the meantime [7]; Alves et al. studied the decomposition method of CO_2 emission intensity from energy consumption in Portugal during 1996 to 2009, and discussed effective ways for energy conservation and emission reduction [8]; Ang and Goh studied power production and its carbon emission in ASEAN countries, focusing on the driving factors of carbon emission intensity, the performance of carbon emission intensity and the future prospect for the change of carbon emission intensity [9]; Jeffrey and Perkins studied the relationship between EU's regional energy tax, participatory carbon emission trading system and CO_2 emission intensity, and believed that energy taxation and carbon emission trading system were conducive to promoting the reduction of carbon emission intensity [10]; Rodríguez and Pena-Boquete studied the change of carbon emission intensity from energy consumption in Newly Industrial Economics, and further studied the design of climate policies in these four countries as well as their experiences and lessons in environmental pollution and control [11]; Pappas et al. found the transfer of energy consumption and carbon emission intensity from China to India and Southeast Asian countries through industries that generated cross-country carbon pollution [12]; Paulo and Iveira-De used IDA-LMDI method to analyze the impact of power generation capacity on carbon emission intensity in Latin America and the Caribbean, and considered that power generation capacity is an important factor affecting carbon emission intensity [13]; Awodumi and Adewuyi analyzed the relationship between energy consumption and carbon emission in the economic development of African oil-producing economies, arguing that oil and natural gas consumption is a major source of carbon emission and advocating for greater energy conservation and emission reduction in the production process [14].

Chinese scholars' studies on carbon emission intensity from energy consumption and the driving factors started relatively late. He and Liu analyzed the carbon emission intensity of greenhouse gas emission index and studied the measurement method [15]; Wang and Huang took Jiangsu Province as an example to study the main driving factors of carbon emission intensity through empirical research [16]; Zhang adopted empirical research to study the impact of changes in economic development mode on carbon emission intensity, concluding that a reasonable choice of economic development mode is conducive to promoting the reduction of carbon emission intensity [17]; Pan et al. analyzed the changes of carbon emission intensity in China's manufacturing industry and the driving factors through empirical research [18]. Sun and Zhang empirically studied the driving factors of carbon emission intensity from China's energy consumption and identified the main factors by using statistical analysis method [19]. Zhang and Zhang analyzed the spatial effect of energy endowment and technological progress on China's carbon emission intensity through empirical study [20]. Yan et al. analyzed the driving factors and regional differences of China's carbon emission intensity by using a combination of multiple methods, and explored effective ways of energy conservation and emission reduction [21]. Li et al. studied the impact of industrial transfer on the carbon emission intensity from regional energy consumption by taking the industrial development in the Tianjin-Hebei region as an object, and further analyzed the improvement measures [22]. Han et al. studied the impact of China's new-type urbanization construction and energy consumption growth on the carbon emission intensity from energy consumption, and analyzed the specific countermeasures to effectively control China's carbon emission intensity [23]. Guo and Zhou studied the astringency of carbon emission intensity from energy consumption in Jiangsu, Zhejiang and Shanghai by using statistical methods, they believed that the CO_2 emission intensity from energy consumption in Zhejiang and Shanghai had no strict astringency on the time axis, and that the CO_2 emission intensity from energy consumption in Jiangsu Province had conditional astringency [24]. Jiang et al. analyzed the current situation of China's energy consumption and carbon emission, and studied the imbalance of China's carbon emission intensity and the driving force of its change, so as to provide a basis for China to formulate a scientific, reasonable, fair and efficient regional emission reduction scheme [25].

From the above analysis, it can be seen that the study scope of carbon emission intensity from energy consumption in developed countries is relatively wide, and various driving factors of carbon emission from energy consumption are deeply studied. However, foreign theories and experience cannot be directly applied to solve the problem of controlling carbon emission intensity from energy consumption in China. Chinese scholars' research on this issue is obviously not deep enough, most of the study methods are regression tests and the period of research data is relatively short which reduces the credibility of the empirical research conclusions and affects the validity of the research results. This paper attempts to combine the changing law of carbon emission intensity from energy consumption, measure carbon emission intensity by using energy chemical structure and combustion carbon emission principle, and introduce the modified Kaya equation to comprehensively study the influencing factors of carbon emission intensity from energy consumption, which can improve the validity of the research. This research can provide a basis for the government in formulating energy conservation and emission reduction policies and guidance to energy consumption departments in their energy conservation and emission reduction efforts.

Materials and Methods

Measurement Method of Carbon Emission Intensity from Energy Consumption

Carbon emission is a proper noun for greenhouse gas emissions, the main gas emitted by greenhouse gases is CO_2, and carbon emission actually refers to CO_2 emission [26]. Carbon emission intensity refers to the scale of CO_2 emission per unit of GDP produced, usually expressed in kg/yuan or ton/ten thousand yuan. It is not only a measure of the extent of carbon emissions from energy consumption in economic development, but also an important indicator for comparing the carbon emission intensity in different countries. It is thus clear that before determining the energy carbon emission intensity, the scale of carbon emission must first be measured, and then the corresponding energy carbon emission intensity can be measured based on the scale of energy carbon emission in different periods and the GDP in the same period [27]. In order to achieve a reasonable and effective measurement of the scale of carbon emissions from energy consumption, this paper adopts the chemical structure of different types of energy combustion and the carbon emission principle from energy combustion for scientific measurement [28].

If there are n different energy forms, the energy consumption of each form is $X_{i,}$ and each form has m states, namely: production quantity (PQ_{ij}), imports quantity (IQ_{ij}), exports quantity (EQ_{ij}), the change of stock quantity (DSQ_{ij}) and other consumption quantity (OQ_{ij}), the form of energy in the opposite direction is denoted by "-" which should be deducted in the total consumption. If Q_i is used to represent the total amount of standard coal after the conversion of the i_{th} energy, and μ_i is used to represent the standard coal conversion coefficient of the i_{th} fuel, there is:

$$Q_{\text{i}} = \sum_{i=1}^{n}\left[\left(PQ_{ij} + IQ_{ij} \pm \Delta SQ_{ij} - EQ_{ij} \pm OQ_{ij}\right)\cdot \mu_i\right] \quad (1)$$

The carbon emission from energy consumption depends on the net carbon emission and the carbon oxidation rate in the process of fuel combustion, and the net carbon emission is equal to the difference between the amount of carbon contained in energy and the amount of carbon sequestered. Since the molecular weight of CO_2 is 44 and the molecular weight of carbon is 12, the carbon emission can be converted to CO_2 emission based on the ratio of carbon molecules. K_i denotes the correction coefficient, which is equal to the ratio of the amount of CO_2 produced by the i_{th} energy consumption to the total amount of CO_2. α_i denotes the carbon content in unit standard calorific value of the i_{th} energy, that is, the potential carbon emission factor. β_i is the carbon sequestration rate of the i_{th} fuel, ξ_i is the carbon oxidation rate of i_{th} energy combustion. Let $X(CO_2)$ denote the scale of carbon emission from energy consumption, then:

$$X(CO_2)=\sum_{i=1}^{n} K_i\left[\xi_i\cdot(\mu_i\alpha_i-\beta_i)\cdot Q_i\cdot(44/12)\right] \quad (2)$$

According to the reference standard coal conversion coefficient of various energy in the Appendix of China Energy Statistical Yearbook and drawing on the latest research results at home and abroad, the parameters in the above estimation model are determined as detailed in Table 1.

The carbon content in the above standard calorific value of energy units is based on the standards of the Intergovernmental Panel on Climate Change (IPCC) and the Organization for Economic Cooperation and Development (OECD).

Construction of Empirical Study Model of Driving Factors

In order to analyze the driving factors of CO_2 emission intensity from energy consumption in China, the Kaya model is reconstructed and decomposed to determine the influencing factors of carbon emission intensity from energy consumption and the improved Kaya model is used to conduct correlation tests on the driving factors of CO_2 emission intensity [29]. Let CO_2 denote carbon dioxide emissions and GDP denote gross domestic product, Q is used to represent energy consumption (tons of standard coal), then Kaya identity can be expressed as:

$$CO_2=\frac{CO_2}{Q}\times\frac{Q}{GDP}\times\frac{GDP}{P}\times P \quad (3)$$

The above formula can be used to study the driving factors of CO_2 and CO_2/P. By converting the above equation, CO_2 can be expressed as: CO_2 = (CO_2/Q) × (Q/GDP) × GDP. Then, by removing the GDP to the left, we can obtain:

$$\frac{CO_2}{GDP}=\frac{CO_2}{Q}\times\frac{Q}{GDP}\Rightarrow CI=CD\times EI \quad (4)$$

Table 1. Estimation model parameters of carbon emission from fuel consumption.

Fuel	Standard coal conversion coefficient (μ_i)	Potential Carbon emission factor (α_i)	Carbon sequestration rate (β_i)	Carbon oxidation rate (ξ_i)
Raw coal	0.7143	27.30	0.30	0.980
Cleaned coal	0.9000	25.80	0.30	0.980
Other washed coal	0.5253	25.80	0.30	0.980
Briquette	0.6068	25.80	0.30	0.980
Coking coal	0.9714	29.50	0.30	0.980
Crude oil	1.4286	29.50	0.80	0.990
Gasoline	1.4714	18.90	0.80	0.990
Kerosene	1.4714	19.60	0.75	0.990
Diesel oil	1.4571	20.20	0.80	0.990
Heavy oil	1.4286	21.10	0.50	0.990
Natural gas	1.3300	15.30	0.33	0.995
Coke oven gas	6.1417	29.50	0.30	0.995
Other coal gas	2.8758	29.50	0.30	0.995
Refinery dry gas	1.5714	20.00	0.50	0.995
Liquefied petroleum gas	1.7143	17.20	0.80	0.990
Other petroleum products	1.3107	20.00	0.80	0.990
Other coal coking products	1.1540	25.80	0.30	0.980
Other energy	--	25.00	0.50	0.990

In the above formula, CI is the carbon emission intensity from energy consumption, CD is the carbon emission multiple (or emission density) from energy consumption, and EI is the energy consumption intensity [30]. If the investment in environmental pollution treatment is taken into account, let IE denote the annual total investment in environmental pollution treatment, then the above formula can be extended to:

$$\frac{CO_2}{GDP}=\frac{CO_2}{Q}\times\frac{Q}{IE}\times\frac{IE}{GDP} \tag{5}$$

In the above formula, (Q/IE) is the ratio between total energy consumption Q and the investment in environmental pollution treatment IE, which reflects the energy consumption intensity of environmental pollution treatment investment and is expressed by QI; (IE/GDP) is the ratio of total investment in environmental pollution treatment IE and annual GDP, reflecting the proportion of environmental pollution treatment investment to unit GDP, which is denoted by GC. If the incremental relationship is considered, the increment in carbon emission intensity from energy consumption is denoted by ΔCI, the increment in carbon emission density from energy consumption is denoted by ΔCD, the increment of energy consumption intensity of environmental pollution treatment investment is denoted by ΔQI, the increment in the proportion of environmental pollution treatment investment to GDP is denoted by ΔGC, then the following formula is established:

$$\Delta CI=\Delta CD\times\Delta QI\times\Delta GC \tag{6}$$

When using the Kaya identity to study industrial CO_2 emission, the above formula can be converted appropriately as follows:

$$CO_2=\sum_{i=1}^{n}\left(\frac{(CO_2)_{ij}}{Q_{ij}}\times\frac{Q_{ij}}{GDP_{ij}}\times\frac{GDP_{ij}}{GDP}\times GDP\right)$$
$$\Rightarrow\sum_{i=1}^{n}(\mathrm{CD}_i\times EI_i\times IR_i\times GDP) \tag{7}$$

In the above formula, CO_2 is the total amount of carbon dioxide emitted by various industries, (GDP_{ij}/GDP) is the ratio of GDP of different industries to the total national GDP. The following formula can be obtained after appropriate transformation:

$$CI=\frac{CO_2}{GDP}=\sum_{i=1}^{n}(\mathrm{CD}_i\times EI_i\times IR_i)=CD\times EI \tag{8}$$

Based on Kaya identity, this paper selects the main driving factors of carbon emission from energy consumption on the basis of comprehensive analysis. Since the equation $CI = CD \times EI$ holds, CI can be decomposed as $[(CO_2/P) \times (P/Q)] \times [(Q/IE) \times (IE/GDP)]$, where P/Q is the reciprocal of per capita energy consumption and is denoted by PE^{-1}. IE/GDP is denoted by IG, K is the correction coefficient, then the following formula is established:

$$CI=K\times PC\times PE^{-1}\times QI\times IG \tag{9}$$

In order to eliminate the heteroscedasticity in the collected statistical data and to reduce the error that may be generated in the technical process of the research data, the natural logarithms of variables on both sides of the identity are taken in the above empirical research equation, then we can obtain the following identity:

$$\ln CI_{it}=\alpha_0+\alpha_1\ln CI_{it-1}\ln \mathrm{PC}-\alpha_2\ln PE+\alpha_3\ln \mathrm{Q}I+\alpha_4\ln \mathrm{IG} \tag{10}$$

In the above formula, α_0 is the constant term of the test equation, $\alpha_i(i = 1, 2, 3, 4)$ are the coefficients of the driving variables of the test equation. The correlation between independent variables and dependent variables can be determined by using regression test method.

Results and Discussion

Analysis of Law of Carbon Emission Intensity from Energy Consumption

In the empirical study, the data to test the model variables are taken from China Statistical Yearbook to analyze and identify indicators of production, imports, exports, and stock increase or decrease of various energy, without considering other consumption. The measurement results of CO_2 emission intensity from energy consumption in China can be calculated by substituting the determined indicators and parameters into Formula (2), and then the carbon emission intensity from energy consumption in China can be calculated after using the GDP data over years from China Statistical Yearbook. The specific measurement results are shown in Table 2.

According to the data in the table above, as China's GDP grows, energy consumption and CO_2 emissions from energy consumption show a synchronous growth trend, with CO_2 emissions from energy consumption growing the fastest and energy consumption growth rate lagging behind GDP growth rate. The relationship between National GDP, the CO_2 emission from energy consumption and energy consumption is shown in the upper part of Fig. 1; The relationship between CO_2 emission intensity from energy consumption and energy consumption intensity is shown in the lower part of Fig. 1.

It can be clearly seen from the upper half of the figure that the carbon emission intensity slowed down from 2013 to 2016 and began to increase after 2017 with the continuous growth of China's economy. The change of carbon emission intensity is mainly the result of the

Table 2. Measurement results of CO_2 emissions and emission intensity from energy consumption in China.

Year	National GDP (100 million yuan)	Energy consumption (Unit: 10 thousand tons of standard coal)	CO_2 emission from energy consumption (10 thousand tons)	CO_2 emission intensity from energy consumption CI (tons/10 thousand yuan)	Energy consumption intensity (tons/10 thousand yuan)
2000	100280	146964	332821	3.3189	1.4655
2001	110863	155547	370634	3.3432	1.4031
2002	121717	169577	409167	3.3616	1.3932
2003	137422	197083	462452	3.3652	1.4341
2004	161840	230281	508947	3.1448	1.4229
2005	187319	261369	537036	2.8670	1.3953
2006	219439	286467	581026	2.6478	1.3055
2007	270092	311442	620836	2.2974	1.1531
2008	319245	320611	670337	2.0980	1.0043
2009	348518	336126	708346	2.0292	0.9644
2010	412119	360648	781419	1.8919	0.8751
2011	487940	387043	826238	1.6886	0.7932
2012	538580	402138	858109	1.5880	0.7467
2013	592963	416913	909062	1.5272	0.7031
2014	643563	425806	920868	1.4300	0.6616
2015	688858	430000	944122	1.3773	0.6242
2016	746395	436000	969826	1.3033	0.5841
2017	832036	449000	1035639	1.2521	0.5396
2018	919281	455000	1097027	1.2185	0.4950
2019	986515	486000	1207914	1.2191	0.4926
2020	1013567	498000	1256532	1.2397	0.4913

combined effect of the continuous growth of GDP and the slowdown of energy consumption growth. From the lower half of the figure, it can be seen that the downward trend in China's carbon emission intensity from energy consumption is mainly caused by the continuous decline of energy consumption intensity, indicating that China's energy conservation and emission reduction has played a decisive role in controlling carbon emission intensity.

Parameter Determination and Related Test of Empirical Model

The above is the linear test model constructed by empirical research in this paper, which is used to analyze the driving factors of carbon emission intensity from energy consumption in China. The basic data of the empirical research is mainly obtained from the China Statistical Yearbook and the China Environmental Status Bulletin from 2000 to 2020, which is analyzed and collated to obtain the final data. The data of carbon emission intensity from energy consumption in the model is measured with the model constructed by the above statistical data, while the other variables are calculated using the base and measurement information. The empirical research data obtained by calculation is shown in Table 3.

Variable Test of Empirical Study

1. Variable stability test. In order to analyze the correlation between the driving factors of carbon emission intensity from energy consumption in China and to determine the main driving factors and the degree of influence, the stability of related time-series variables is required to be tested firstly. The stability of variables is tested by examining statistics such as the mean, variance and auto-covariance to determine whether the variables have changed over time. The criteria of the test must meet the following three conditions: (1) Variable mean is a time-independent constant: $E(\bar{X}) = \mu$; (2) Variable variance is a time-independent constant: $VaR = \sigma^2$; (3) Variable auto-covariance is a constant that is related to the lag order ι of the time-series variable and is independent of the time variable t: $C_{ov}(X_t, X_{t-1}) = \lambda\iota$. In this paper, ADF test and PP test are selected for testing. In order

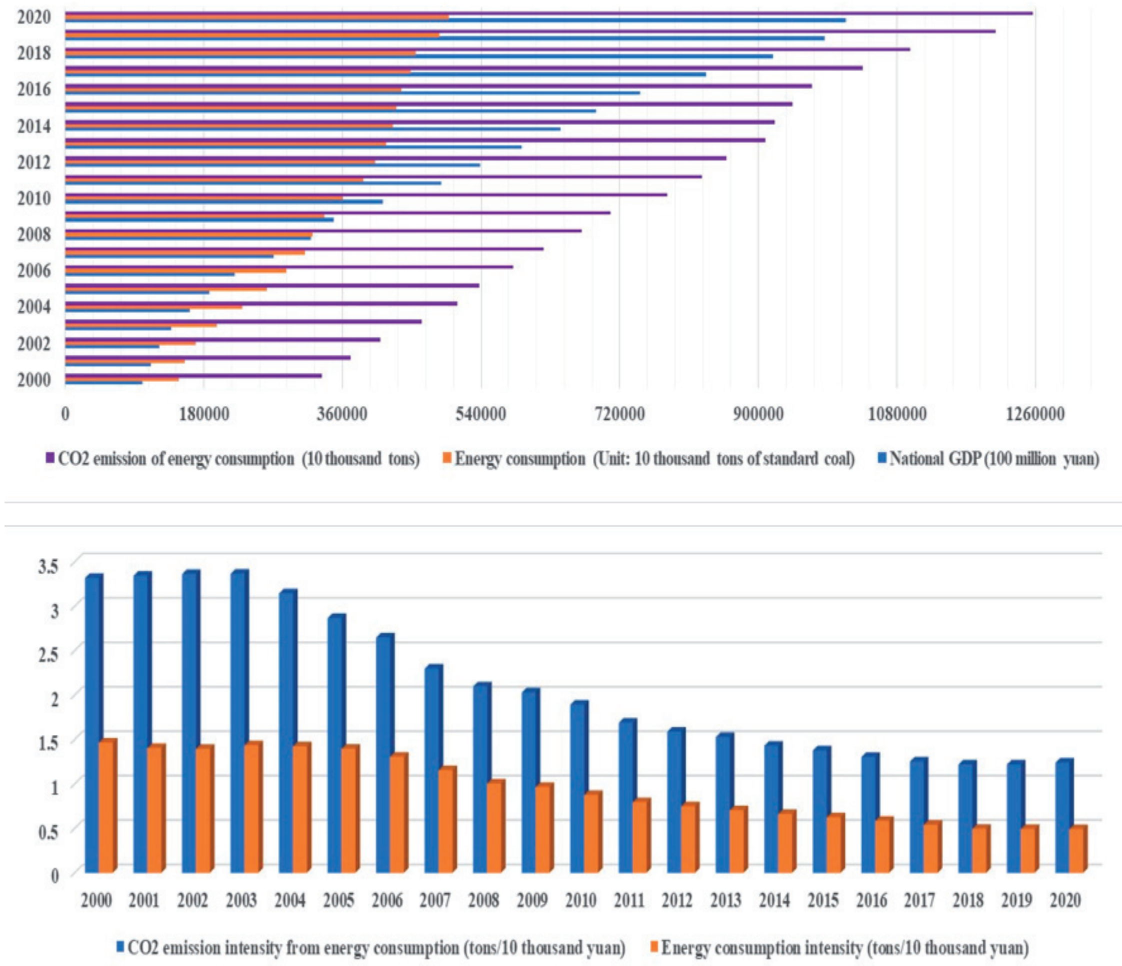

Fig. 1. Relationship between carbon emission intensity from energy consumption and main relevant indicators.

to eliminate the heteroscedasticity between variables, logarithmic processing has been carried out. The results of variable stability test by using EVIEWS software are shown in Table 4.

It can be seen from the above table that the four variables of the empirical model in this paper are all in compliance with the requirements of stability through ADF test and PP test. In the first-order difference statistic test in the table above, only the 1% level of significance is tested, there is no necessary to relax the test requirements since the test results are all in compliance with the requirements.

2. Lag order test. The lag order test is for the co-integration test. Since the co-integration test adopts Johansen method which is the maximum likelihood estimation of vector auto-regression (VAR), it is necessary to first determine the reasonable lag order of the VAR model. To eliminate the auto-correlation of the error term of the equation, the selection of lag order should satisfy both the lag term of the equation and the degree of freedom of the variables. The lag order (length) of the unrestricted model test is selected as 3, and the lag period of the test is 2. If the entire unit roots fall within the unit circle, it indicates that the VAR model established with the variables in this paper is stable and that the empirical model variables have no sequence correlation. The matrix of empirical research results are as follows:

$$\begin{pmatrix} & AICC & HQC & AIC & SC & FPEC \\ Lag\,order1 & -36.2176 & -36.8127 & -33.4516 & -34.4516 & 2.9123E-12 \\ Lag\,order2 & -35.8736 & -37.2731 & -34.6625 & -35.6721 & 1.8527E-12 \\ Lag\,order2 & -34.8128 & -36.2175 & -31.8675 & -36.1645 & 3.0137E-12 \end{pmatrix}$$

The test proves that the empirical test model constructed in this paper is stable, and the variables do not have sequence correlation, allowing for co-integration test of variables.

3. Co-integration test. The purpose of the co-integration test is to determine that the equation variables have the same order characteristics. According to Granger's Co-integration Theory and the results of empirical research data analysis, Johansen-Juselius co-integration test is adopted on equation variables. The test results are shown in Table 5.

According to the results of Johansen-Juselius co-integration test above, equation variables have the same order characteristics, which prove the validity of the empirical equation. Based on this, the parameters of

Table 3. Basic data for analysis of driving factors of carbon emission intensity from energy consumption.

Year	National population (10 thousand)	Environmental pollution treatment investment (100 million yuan)	PC (tons/10 thousand yuan)	PE (yuan/ton)	QI (tons/10 thousand Yuan)	IG (%)
2000	126743	1014.90	2.6260	1.1595	144.8016	1.0121
2001	127627	1106.70	2.9040	1.2188	140.5481	0.9983
2002	128453	1367.20	3.1853	1.3201	124.0387	1.1233
2003	129227	1627.70	3.5786	1.5251	121.0800	1.1845
2004	129988	1908.60	3.9153	1.7716	120.6564	1.1793
2005	130756	2388.00	4.1072	1.9989	109.4451	1.2748
2006	131448	2566.00	4.4202	2.1793	111.6445	1.1693
2007	132129	3387.30	4.6987	2.3571	91.9456	1.2535
2008	132802	4937.03	5.0476	2.4142	64.9393	1.5452
2009	133450	5258.39	5.3080	2.5187	63.9223	1.5064
2010	134091	7612.19	5.8275	2.6896	47.3776	1.8430
2011	134735	7114.03	6.1323	2.8726	54.4070	1.4539
2012	135404	8253.46	6.3374	2.9699	48.7234	1.5274
2013	136072	9037.20	6.6807	3.0639	46.1340	1.5182
2014	136782	9575.50	6.7324	3.1130	44.4682	1.4869
2015	137462	8806.30	6.8993	3.1281	48.8281	1.2846
2016	138271	9219.80	6.9254	3.1826	47.2903	1.2390
2017	139008	9538.95	7.4502	3.2300	47.0702	1.1533
2018	139538	9887.32	7.8691	3.2638	46.0185	1.0982
2019	140005	9600.00	7.9743	3.3981	45.9762	1.0763
2020	141178	9450.00	8.0216	3.4107	45.8651	1.4764

the empirical equation can be determined and tested by using SAS9.4 software.

4. Determination and test of equation parameters of empirical study. The empirical study equation reflects the relationship between dependent and independent variables, determination of parameters can be used to predict the carbon emission intensity from energy consumption, and the relationship between dependent and independent variables can be found through the test of variables and parameters. According to the results

Table 4. Results of variable stability test of the model.

Variables	ADF test method		PP test method		Result
	Test value	Probability	Test value	Probability	
Ln PC	-1.3841	0.3648	-1.3216	0.9127	Unstable
Ln PE	-1.4218	0.4327	-1.3947	0.8916	Unstable
Ln QI	-0.5428	0.9027	-0.5219	0.6816	Unstable
Ln IG	0.7628	0.5029	-0.7236	0.4519	Unstable
Dln PC	-3.2458	0.0025	-3.2346	0.0046	Stable
Dln PE	-3.3517	0.0045	-3.3158	0.0058	Stable
Dln QI	-2.6428	0.0065	-2.5485	0.0079	Stable
Dln IG	-3.0516	0.0016	-2.8728	0.0028	Stable

Table 5. Results of Johansen co-integration test.

Test category	H_0: Rank = r	H_0: Rank = r	Characteristic root	Maximum	P_r>Maximum eigenvalue
Maximum characteristic root test	0	1	0.7137	417.25	0.0068
	1	2	0.6215	383.18	0.0807
	2	3	0.2726	269.94	0.1129
	3	4	0.1749	169.28	0.0629
Trajectory test	0	1	0.7137	507.26	0.0051
	1	2	0.6215	413.38	0.0681
	2	3	0.2726	298.94	0.0974
	3	4	0.1749	209.18	0.0561

of the above analysis, the logarithmic results of dependent and independent variables are calculated, which are shown in Table 6.

The above are the results after taking natural logarithm of dependent and independent variables in the empirical research equation. The coefficient of the equation is determined by SAS9.4, the coefficients and the standard deviations of 1% level are: α_0 = -4.5329; σ_0 = 0.1259; α_1 = 0.9853; σ_1 = 0.0557; α_2 = -0.9875; σ_2 = 0.0394; α_3 = 0.9883; σ_3 =0.0159; α_4 = 0.9724; σ_4 = 0.01569. Other parameters are as follows: T = (2000, 2016), R2 = 0.9998, $\bar{R}^2$ = 0.9968, F = 16027.76. According to the above results, the specific expression of the test equation can be determined, and the variable coefficient of the above equation can be substituted into Formula (9) to determine the long-term

Table 6. Natural logarithm results of basic data of carbon emission driving factors.

Year	ln CI	ln PC	ln PE	ln QI	ln IG
2000	1.1996	0.9655	0.1480	4.9754	0.0120
2001	1.2069	1.0661	0.1979	4.9455	-0.0017
2002	1.2124	1.1585	0.2777	4.8206	0.1163
2003	1.2135	1.2750	0.4221	4.7965	0.1693
2004	1.1458	1.3649	0.5719	4.7929	0.1649
2005	1.0533	1.4127	0.6926	4.6954	0.2428
2006	0.9737	1.4862	0.7790	4.7153	0.1564
2007	0.8318	1.5473	0.8574	4.5212	0.2259
2008	0.7410	1.6189	0.8814	4.1735	0.4352
2009	0.7076	1.6692	0.9237	4.1577	0.4097
2010	0.6376	1.7626	0.9894	3.8581	0.6114
2011	0.5239	1.8136	1.0552	3.9965	0.3742
2012	0.4625	1.8465	1.0885	3.8862	0.4236
2013	0.4234	1.8992	1.1197	3.8316	0.4175
2014	0.3577	1.9069	1.1356	3.7948	0.3967
2015	0.3201	1.9314	1.1404	3.8883	0.2504
2016	0.2649	1.9352	1.1577	3.8563	0.2143
2017	0.2248	2.0082	1.1725	3.8516	0.1426
2018	0.1976	2.0629	1.1829	3.8290	0.0937
2019	0.1981	2.0762	1.2232	3.8281	0.0735
2020	0.2149	2.0821	1.2269	3.8257	0.3896

equilibrium equation between each specific variable and the carbon emission intensity from energy consumption:

$$\ln CI = -4.5329 + 0.9853 \ln PC + 0.9875 \ln PE + 0.9883 \ln QI + 0.9724 \ln IG$$

5. Determination of error correction model. According to the Co-integration Theory, when *ln PC*, *ln PE*, *ln QI* and *ln IG* these four empirical variables pass the co-integration test, there may be short-term non-equilibrium effects among the variables which can be expressed by the error correction model. According to the theory of Vector Error Correction Model (VECM) established by Engle and Granger (1987), if X_i is a co-integration vector, then:

$$\Delta X_t = k\xi' X_{t-1} + \sum_{i=1}^{P-1} \Gamma_i \Delta X_{t-i} + \varepsilon_t \quad (t = 1, 2, 3, \ldots, n) \tag{11}$$

This equation can be expressed by the error correction model. Where $ecm_{t-1} - \xi' X_{i-1}$ is the error correction term for the test equation, which determines the error size; *K* in the formula is the adjustment coefficient, which determines the error adjustment speed of the driving factors; *P* is the order of the equation, *i* is the time-series variable, and the specific expression of the error correction model is as follows:

$$\Delta X_t = kecm_{t-1} + \sum_{i=1}^{P-1} \Gamma_i \Delta X_{t-i} + \varepsilon_t \tag{12}$$

According to the vector error principle, the variables corresponding to the co-integration relationship of the equation are: *Δln PC*, *Δln PE*, *Δln QI*, *Δln IG*, etc. The vector error correction model is established to correct the error caused by the influence of independent variable changes on the carbon emission intensity from energy consumption. Using the original data and according to the above analysis results, the value of *P* is 2, thus the correction model is relatively simple. The parameters of the error correction model and the test results are determined with the SAS9.4 software, the results of equation coefficients and standard deviations at 1% level are: β_0 = 0.0074, σ_0 = 0.0016; β_1 = 0.8913, σ_1 = 0.0810; β_2 = -0.9854, σ_2 = 0.0627; β_3 = 1.0078, σ_3 = 0.0510; β_4 = 1.0169, σ_4 = 0.0571. The results of other parameters are: T = (2000, 2016), R_2 = 0.9786, $\bar{R}^2$ = 0.9628, F= 125.77. According to the correction equation test Formula (12) and determined parameters of correction equation, the specific expression of the correction equation can be determined. The condition of the correction equation can be estimated by the standard deviation and the test results of other parameters. Since there is difference in sign between the variables *Δln PE* and $\Delta \ln PE^{-1}$, the error correction equation is as follows:

$$\Delta \ln CI = 0.8913 \Delta \ln PC + 0.9854 \Delta \ln PE_{t-1} + 1.0078 \Delta \ln QI_{t-2} + 1.0169 \ln \Delta IG - 0.0074 ecm_{t-1}$$

The above correction model reflects the influence of short-term changes of each specific driving factor on the carbon emission intensity from energy consumption, and short-term countermeasures can be proposed for energy conservation and emission reduction through short-term equilibrium analysis.

Discussion of Empirical Study Results

According to the results of the above empirical test, the analysis is based on long-term trend. In this

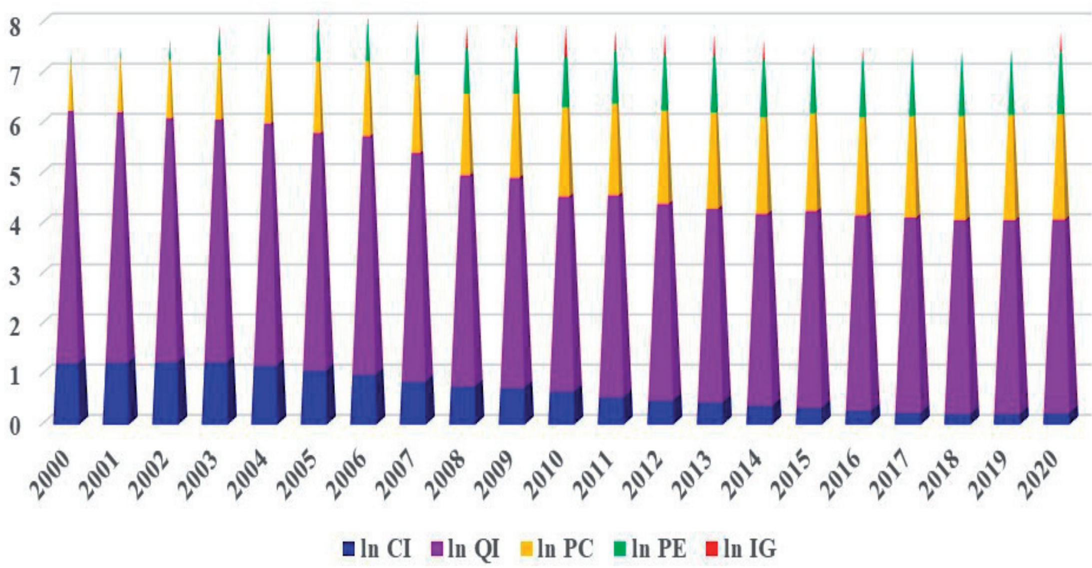

Fig. 2. Relationship between dependent variables and independent variables in empirical research model.

paper, Kaya method is used for factor decomposition, and the four main driving factors of carbon emission intensity from energy consumption (*CI*) are determined as follows: per capita CO_2 emission intensity (*PC*), per capita energy consumption (*PE*), energy consumption intensity of environmental pollution treatment investment (*QI*) and the proportion of environmental pollution treatment investment to GDP (*IG*). The variation trend and correlation of the above five variables are drawn in the rectangular coordinate system, as shown in Fig. 2.

This study conducted a co-integration test on the independent variables of the model. All four variables tested for co-integration tests have a significant influence on the carbon emission intensity from energy consumption and show a positive influence on the CO_2 emission intensity from energy consumption. According to the regression coefficient results of the co-integration equation, the influence elasticity for each of the four variables are: 0.8913, 0.9854, 1.0078 and 1.0169. Considering that there are differences in the trends of variables, the conclusions of the empirical study are as follows: Since the actual trend of per capita CO_2 emission is opposite to that of carbon emission intensity from energy consumption, the influence elasticity means that the carbon emission intensity from energy consumption decreases by 0.8913% for every 1% increase in energy consumption per capita, indicating that the growth rate of China's GDP is much higher than that of carbon emission from energy consumption; Since the reciprocal of per capita energy consumption has the same trend as the actual change in carbon emission intensity from energy consumption, while per capita energy consumption and its reciprocal show reverse changes, the meaning of influence elasticity is that for every 1% increase in per capita energy consumption, the carbon emission intensity from energy consumption drops by 0.9854%, indicating that the growth rate of China's GDP is much greater than the growth rate of energy consumption; Since the actual trends of energy consumption intensity of environmental pollution treatment investment and carbon emission intensity from energy consumption are the same, the implication of influence elasticity is that the carbon emission intensity from energy consumption decreases by 0.9854% for every 1% decrease of energy consumption intensity of environmental pollution treatment investment, indicating that the growth of environmental pollution treatment investment promotes the decrease of carbon emission intensity from energy consumption; Since the actual trend of the proportion of environmental pollution treatment investment to GDP is opposite to that of carbon emission intensity from energy consumption, the meaning of influence elasticity is that the carbon emission intensity from energy consumption decreases by 1.0169% for every 1% increase in the proportion of environmental pollution treatment investment to GDP, indicating that both economic growth and the increase in environmental investment can promote the decrease of carbon emission intensity from energy consumption.

According to the test results analysis of short-term error correction model, the changes in carbon emission from energy consumption are caused by changes in four incremental factors: *Δln PC*, *Δln PE, Δln QI*, and *Δln IG*. The impact status is basically the same as that of the long-term model, all the incremental driving factors have a positive impact on the incremental of carbon emission intensity from energy consumption, and the influence elasticity are: 0.8913, 0.9854, 1.0078 and 1.0169. The incremental in the proportion of environmental pollution treatment investment to GDP has the greatest impact on the increment of short-term energy consumption intensity, followed by: the increment of energy consumption intensity of environmental pollution treatment investment, the reciprocal of per capita energy consumption and per capita carbon emission. From the coefficients and test results, it can be seen that the equilibrium of positive influence and negative influence is mainly caused by the error adjustment term ecm_{t-1}, which adjusts the unbalanced state of carbon emission from energy consumption back to the equilibrium state at a rate of 0.0074.

Conclusions

In order to explore effective methods to reduce the carbon emission intensity from energy consumption in China, based on literature review and current situation analysis, this paper adopted the method of combining the chemical structure and energy combustion principle to scientifically measure the CO_2 emission and emission intensity from energy consumption. The change of carbon emission intensity of China's energy consumption is analyzed by means of measurement results and trend chart. On this basis, Kaya identity is modified through the systematic analysis of Kaya method and full consideration of the actual situation in China. Four independent variables were chosen to establish the empirical test model of driving factors of carbon emission intensity from energy consumption in China: per capita CO_2 emission, per capita energy consumption, energy consumption intensity of environmental pollution treatment investment and the proportion of environmental pollution treatment investment to GDP. After stability test, lag order test and co-integration test, the variable long-term equilibrium equation and error correction equation were determined. The study found that the four driving factors all have a positive impact on the carbon emission intensity from energy consumption, and the energy consumption intensity of environmental pollution treatment investment has the largest impact on the carbon emission intensity from energy consumption, followed by per capita energy consumption, per capita carbon emission and the proportion of environmental pollution treatment investment to GDP.

Based on the research results, the following recommendations are made. First, the government should gradually expand the scale of environmental governance investment, increase the proportion of environmental governance investment in GDP and promote the transformation of China's environmental pollution from energy consumption to "inverted U"; Secondly, energy conservation and emission reduction is an effective way to control the carbon emission intensity from energy consumption, therefore per capita energy consumption, especially coal resources, should be gradually reduced; Finally, it is important to pay attention to the influential attributes of the driving factors, grasp the main factors and take comprehensive actions to promote the continuously reduction of carbon emission intensity from energy consumption and realize the sustainable economic development in China. It is worth noting that energy conservation and emission reduction is a long-term task, which should be carried out in a planned way to facilitate the gradual achievement of long-term control objectives.

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Conflict of Interest

The authors declare no conflict of interest.

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