Pol. J. Environ. Stud. Vol. 31, No. 5 (2022), 4413-4425

DOI: *10.15244/pjoes/147823* ONLINE PUBLICATION DATE: 2022-06-20

Original Research

Research on the Impact of Industrialization and Urbanization on Carbon Emission Intensity of Energy Consumption: Evidence from China

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Received: 7 February 2022
Accepted: 29 March 2022

Abstract

In order to explore effective ways for energy conservation and emission reduction, seven correlated variables are selected in this paper according to the government statistics with the extended STIRPAT model, and the impact of China's industrialization and urbanization on carbon emission intensity of energy consumption is studied. The study found that urbanization rate and urban population employment rate are the main factors affecting per capita carbon emission of energy consumption in China; the industrialization has a reverse impact on per capita carbon emission of energy consumption, indicating that China's industrialization is relatively low and is not the main factor affecting per capita carbon emission of energy consumption; the service industry added value rate and the agricultural industry added value rate also have reverse effects on China's per capita carbon emission of energy consumption, and the degree of impact is relatively small. Therefore, China is supposed to develop industry vigorously in the future, to appropriately control the development speed of urbanization and to increase the agricultural industry added value rate moderately, so as to achieve effective control of per capita carbon emission intensity of energy consumption.

Keywords: carbon emission intensity, industrialization, urbanization, energy consumption, empirical research

Introduction

The rapid economic development of China has promoted the improvement of industrialization and urbanization. Industrialization refers to the process in which the proportion of industrial added output value and the added output value of the secondary industry to gross domestic product (GDP) continues to rise, and the proportion of industrial employment to total employment in the country continues to rise; according to international standards, industrialized country should reach 60% industrialization level, over 50% industrial employment rate, and achieve more than 80% in late periods. In 2020, the proportion of the industrial industry added value to GDP in China was 37.80%, and the proportion of the service industry added value to GDP was 54.50%. Considering only the proportion

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of industry to GDP, China has not yet entered the ranks of industrialized countries. China's secondary industry is a service industry developed on the basis of agriculture and industry, and has the nature of non-agricultural development. Taking into account the gross industrial output value in a broad sense, China's industrialization rate has reached 92.30%; urbanization refers to the process of gradually developing from agriculture in the primary industry to industry and service industries, and the proportion of urban population to the country's total population is usually referred to as the urbanization rate indicator, and another indicator is the ratio of agricultural output to GDP. The international recognized standards for urbanized countries are as follows: over 50% urbanization rate and less than 10% agricultural industry added value rate. In 2020, China's urbanization rate was 63.89%, and the proportion of agricultural added value to GDP was 7.7%, indicating that China had already become an urbanized country. On the one hand, the development of industrialization and urbanization in China has promoted the rapid development of economy; China's GDP reached 101598.60 billion yuan in 2020, ranked the second in the world and accounted for 17% of the global GDP. On the other hand, with the rapid economic growth, China's energy consumption and CO_2 emissions are also rising sharply; the national total energy consumption was 4.98 billion tons of standard coal in 2020 which accounted for 26.13% of global total energy consumption, and the total CO_2 emissions was about 12.56 billion tons or 8.85 tons per capita which accounted for more than 30% of global total emission. In this case, China's industrialization and urbanization construction has become the main influencing factor of carbon emission intensity of energy consumption, to a large extent determines the scale and trend of China's carbon emission intensity of energy consumption. In September 2020, Xi Jinping made a "dual carbon" target commitment at the general debate of the United Nations General Assembly, which means that China's environmental regulations and carbon emission constraints will be increasingly strengthened. In this context, it is particularly important and urgent to study the impact of China's industrialization and urbanization on the carbon emission intensity of energy consumption.

Overseas developed countries have studied this issue earlier, and there have been a lot of research results. Intaniwet and Chaiyat analyzed the relationship between economic growth and energy consumption in Greece, and believed that energy consumption was the main driving force of economic growth and also an important cause of environmental pollution in industrialized countries, and this phenomenon would become more and more serious with the improvement of a country's industrialization degree [1]. Parikh and Shukla studied the phenomenon of greenhouse gas effects caused by economic development and increased energy consumption in the process of urbanization in developed countries, they believed that energy consumption would also accelerate with the rapid growth of economy during the process of urbanization and CO_2 emissions from a large amount of energy combustion would pollute the living environment of human beings and cause serious economic losses [2]. Bart Davis et al. studied the use of a combination of natural gas and fuel to replace fossil energy in the United States in the late 19th century, which promoted the substantial decline of energy consumption scale and carbon emission intensity in America [3]. Chung et al. found following conclusions after analyzing two stages in the urbanization process of South Korea: the process of urbanization construction from 1951 to 1980 caused serious damage to the environment due to the lack of experience and irregular development; while during the process of urbanization from 1971 to 2000, the environment pollution caused by urbanization was not serious because the increasing investment in environmental pollution control [4]. Fan et al. analyzed the influencing factors of CO_2 emissions and believed that urbanization rate, industrialization degree and technological progress are the main factors affecting the intensity of CO_2 emissions [5]. Enevoldsen et al. studied industrial energy consumption and CO_2 emissions in Scandinavia by using the decoupling model and considered energy consumption was the main factor that generating CO_2 emissions, and the effective way to reduce CO_2 emissions was to reduce energy consumption [6]. Poumanyvong and Kaneko adopted the method of large-area comparative study and proved that urbanization construction could reduce energy consumption to a certain extent and could reduce CO_2 emissions under the promotion of urbanization [7]. Zarzoso and Maruotti used evidence from China to study the impact of urbanization on carbon emission of energy consumption, and believed that urbanization would increase energy consumption and ultimately leads to an increase in carbon intensity [8]. Neil et al. compared the differences of energy consumption in the process of urbanization between India and China by using the IPETS model, and believed that the urbanization construction in India and China would both promote the increase of energy consumption and ultimately lead to environmental pollution [9]. Sadorrsky studied the impact of industrialization and urbanization on energy consumption intensity in developing countries, and believed that industrialization and urbanization would both promote the reduction of energy consumption intensity and improve energy utilization efficiency, but the scale of energy emission would keep increasing [10]. Brännlund et al. analyzed the current situation of carbon intensity in the process of industrial development in Sweden and the impact of corresponding climate policies on Carbon intensity [11]. Su and Ang used the input-output method to analyze the current situation and changing laws of carbon emission intensity from the perspective of energy consumption, and put forward some effective energy-saving and emission-reduction measures according to the analysis results [12]. Thomakos and Alexopoulos introduced CO_2 emission intensity into environmental performance assessment and made it an important part of Environmental Performance Index, which was conducive to highlighting the reduction of carbon emission intensity in environmental performance assessment and emphasizing the actual effect of environmental performance assessment [13]. Khan et al. studied the greenhouse gas emission status from power system in the process of carbon emission intensity variation, and believed that the losses of greenhouse gas emission would decrease with the reduction of carbon emission intensity [14]. Ghazalia and Ali used the panel data from 1990 to 2012 and adopted the method of empirical research to test the impact of GDP growth, trade development, urbanization and industrialization on energy consumption-generated and greenhouse gas emissions in 147 countries, and concluded that there is a positive correlation [15]. Mahmood et al. used empirical research methods to test the correlation of per capita carbon emissions in Saudi Arabia. It is considered that urbanization and industrialization are the main reasons for the increase in carbon intensity per capita, and the best control strategy is energy conservation and emission reduction [16, 17].

The research on the relationship between urbanization, industrialization and energy consumption carbon emission intensity by Chinese experts and scholars started relatively late, and most research focused on learning from foreign practice and experience. Jiezhong Guo analyzed the relationship between industrialization and urbanization in China and ecological protection and emphasized that environmental protection should be strengthened in China's industrialization and urbanization construction, which mainly achieved by relying on policy support and energy conservation and emission reduction [18]. Zudan Lv studied the impact of China's urbanization process on carbon emission intensity, and believed that urbanization would promote energy consumption, reduce carbon emission intensity and increase carbon emissions at the same time [19]. Heng Ma studied the impact of China's industrialization and urbanization on energy consumption, believed that industrialization and urbanization both promoted economic development and the increase of energy consumption, and energy conservation and emission reduction could be achieved by adjusting industrial structure and promoting technological progress to minimize CO_2 emissions of energy consumption [20]. Zhengge Tu and Renjun Shen studied the impact of China's industrialization and urbanization on energy intensity by using LMDI factor decomposition method, and believed that with the development of China's industrialization and urbanization, the dynamic marginal carbon emission from China's energy consumption would gradually decrease [21]. Tao Sun and Tianyan Zhao studied the measurement method of carbon emissions of energy consumption, and analyzed the formation principle of carbon emission intensity of energy consumption and effective ways for energy conservation and emission reduction [22]. Shaofu Zhou and Yanan Wang studied the impact of industrialization and urbanization on energy consumption intensity, and believed that industrialization and urbanization in different regions and development stages of China had different influences on energy consumption intensity, and formulate differentiated control strategies according to different specific situations [23]. Zhang Wei et al. analyzed the relationship between industrial structure upgrading, energy structure optimization and low-carbon development of industrial system, used the method of empirical research to analyze the influencing factors of carbon emission intensity of energy consumption, and formulated corresponding countermeasures for energy conservation and emission reduction [24]. Shijin Wang studied the impact mechanism of China's new-type urbanization construction on carbon emission of energy consumption, and conducted a systematic analysis of regional differences and influencing factors of carbon emission by using the empirical research method [25]. Xiuyan Han et al. analyzed the relationship between new-type urbanization construction, energy consumption growth and the control of carbon emission intensity, conducted the correlation test of main influencing factors with the method of empirical research, and proposed some specific countermeasures based on the results of empirical research [26]. Qiang Wang et al. compared the carbon emissions in the industrialization and urbanization construction of China and India, and believed that carbon emissions would not increase with economic growth as a future trend, and neither China nor India has reached this target at present [27]. From the perspective of industrialization and urbanization, Feng Dong et al. studied the formation process of carbon dioxide emission peak in developed economies and the specific methods to determine the peak [28, 29]. Tong et al. used empirical research methods to measure the driving effects of carbon emissions in different development stages of China's industrialization, and explored effective measures to reduce carbon emission intensity in the process of industrialization [30, 31].

Through the above literature review, it can be found that developed countries have studied this issue in depth. However, the experience of developed countries cannot be directly applied to the practice process in China. Domestic research is still in the preliminary exploration stage, and the empirical research on the influencing factors is not standardized enough and lacks the feasibility of reference. At present, China's research on this issue is mostly carried out separately, mostly analyzing the impact of energy consumption on carbon emission intensity in the process of urbanization, or studying the impact of energy consumption on carbon emission intensity in the process of industrialization. However, there are relatively few studies on the joint effects of industrialization and urbanization on the carbon intensity of energy consumption. So, this paper attempts to study the impact of China's industrialization and urbanization on the carbon emission intensity of energy consumption, determines the correlation between relevant variables by empirical research method, and formulates effective strategies for energy conservation and emission reduction based on the results of correlation analysis.

Materials and Methods

Variable Selection and Model Construction of Empirical Research

STIRPAT is the earliest foreign method for studying the impact of human production activities on the environment. It is an abbreviation of returning to the random impact of population, wealth and technology on the environment. This model is extended by York based on the classic IPAT model [29], the basic expression of IPAT model is:

$$I = P \times A \times T \tag{1}$$

Where, I is the impact of human activities on nature, which is generally considered as the emission of pollutants, this is carbon emissions; P is the population size, after dividing both sides of the equation by the population size, the equation becomes: $I/P = A \times T$, I/P on the left side of the equation is per capita CO_2 emission from energy consumption, expressed as PECE; A is the assets level, usually expressed in terms of GDP per capita, and T is technological progress or policy support. Based on this model, York et al. first proposed STIRPAT model through improvement, and the specific expression is as follows:

$$I = a \times P^b \times A^c \times T^d \times e \tag{2}$$

In the equation, coefficient is the constant term of the model, b, c and d are the exponential term, and e is the error term. This is the classic STIRPAT model. Therefore, STIRPAT's model is an extension of the IPAT model. With the rapid development of social economy, the production behavior of human beings has undergone great changes, so this model is now out of line with the actual situation and needs to be improved; according to the research needs, and the following variables are selected in this paper on the basis of comprehensive analysis: Per capita carbon emission of energy consumption (PECE) refers to the ratio between the total amount of carbon dioxide emitted by energy consumption and the total population in the same period (tons / person); Per capita energy consumption (PEC) refers to the ratio between the total energy consumption and total population in the same period (ton/person); Industrialization rate (IR) refers to the ratio between the proportion of the added value of industrial industry to GDP (%); Industrial employment rate (IER) refers to the proportion of industrial employment to total employment in the country (%); Urbanization rate (UR) refers to the ratio between the proportion of urban population to total population (%); Urban population employment rate (UER) refers to the ratio between the proportion of urban employment to urban total population (%); Service industry added value rate (SR) refers to the ratio between the proportion of the added value of the service industry to GDP (%); Agricultural industry added value rate (AR) refers to the ratio between the proportion of the added value of agricultural industry to GDP (%). According to the principle of STIRPAT model, the research requirements for the impact of China's industrialization and urbanization on carbon emission from energy consumption are fully taken into account. A multivariable linear regression test model is established with variables selected above as follows:

$$PECE_t = \alpha \cdot PEC_t^{\beta_1} \cdot IR_t^{\beta_2} \cdot IER_t^{\beta_3} \cdot UR_t^{\beta_4} \cdot UER_t^{\beta_5} \cdot SR_t^{\beta_6} \cdot AR_t^{\beta_7} \tag{3}$$

The above is the empirical research model of the influencing factors of China's industrialization and urbanization on the carbon emission intensity of energy consumption, which considers seven influencing factors such as: PEC, IR, IER, UR, UER, SR and AR etc. α is the constant term of the regression test equation. In order to eliminate the heteroscedasticity in the statistical data, and also to reduce the error that research data may generate in the process of technology processing at the same time, the research experiences of experts and scholars at home and abroad are drawn for reference in this paper, and the equation is modified by taking natural logarithm on both sides of the above empirical research equation. The modified empirical research equation is as follows:

$$\begin{aligned} ln\,PECE_t = \beta_0 + \beta_1 ln\,PEC_t + \beta_2 ln\,IR_t + \beta_3 ln\,IER_t + \beta_4 ln\,UR_t \\ + \beta_5 ln\,UER_t + \beta_6 ln\,SR_t + \beta_7 lnAR_t + \varepsilon_t \end{aligned} \tag{4}$$

Where, $\beta_0 = ln\ \alpha$, and ε_t is the degree of freedom of the regression test equation. The multiple linear regression equation is used to test the correlation of the main influencing variables, to determine the degree of correlation between the independent variable and the dependent variable, and to determine the nature and degree of each influencing variable according to the test results.

Calculation of Carbon Emission Intensity

There are two forms of carbon emission intensity, per capita CO_2 emission and CO_2 emission per ten thousand yuan of GDP; in order to reduce the influence of comprehensive factors, the index of per capita CO_2 emission is selected [30]. Per capita energy consumption

Table 1. Basic data of the subject research.

Year	$PECE_t$	PEC_t	IR_t	IER_t	UR_t	UER_t	SR_t	AR_t
1996	2.3023	1.1046	0.4750	0.2352	0.2937	0.5340	0.3280	0.1970
1997	2.3841	1.0994	0.4750	0.2373	0.2992	0.5268	0.3420	0.1830
1998	2.4640	1.0916	0.4620	0.2353	0.3040	0.5195	0.3620	0.1760
1999	2.5442	1.1175	0.4580	0.2304	0.3089	0.5123	0.3780	0.1640
2000	2.6260	1.1595	0.4580	0.2255	0.3622	0.5043	0.3900	0.1520
2001	2.9040	1.2188	0.4480	0.2231	0.3766	0.5019	0.4120	0.1400
2002	3.1853	1.3201	0.4450	0.2146	0.3909	0.5131	0.4220	0.1330
2003	3.5786	1.5251	0.4560	0.2162	0.4053	0.5208	0.4200	0.1230
2004	3.9153	1.7716	0.4590	0.2254	0.4176	0.5328	0.4120	0.1290
2005	4.1072	1.9989	0.4700	0.2382	0.4299	0.5450	0.4130	0.1160
2006	4.4202	2.1793	0.4760	0.2525	0.4390	0.5583	0.4180	0.1060
2007	4.6987	2.3571	0.4690	0.2681	0.4494	0.5607	0.4290	0.1020
2008	5.0476	2.4142	0.4700	0.2723	0.4568	0.5644	0.4290	0.1020
2009	5.3080	2.5187	0.4600	0.2782	0.4659	0.5765	0.4440	0.0960
2010	5.8275	2.6896	0.4650	0.2873	0.4750	0.5779	0.4420	0.0930
2011	6.1323	2.8726	0.4650	0.2954	0.5127	0.5799	0.4430	0.0920
2012	6.3374	2.9699	0.4540	0.3036	0.5257	0.5813	0.4550	0.0910
2013	6.6807	3.0639	0.4420	0.3012	0.5370	0.5940	0.4690	0.0890
2014	6.7324	3.1130	0.4310	0.2993	0.5477	0.6068	0.4830	0.0860
2015	6.8993	3.1281	0.4080	0.2934	0.5610	0.6195	0.5080	0.0840
2016	6.9254	3.1826	0.3960	0.3125	0.5735	0.6224	0.5240	0.0810
2017	7.4502	3.2300	0.3990	0.2848	0.5852	0.6314	0.5270	0.0750
2018	7.8691	3.3253	0.3970	0.2897	0.5958	0.6468	0.5330	0.0700
2019	7.9743	3.3826	0.3860	0.2746	0.6060	0.6507	0.5430	0.0710
2020	8.0216	3.4561	0.3780	0.2647	63.89	0.6848	0.5450	0.0770

carbon emission (PECE) is the proportion of total CO_2 emissions from energy consumption to total population in the same period. Carbon emission is a specific term for greenhouse gas emission, and greenhouse gas carbon emission actually refers to CO_2 emissions. According to the relevant methods and statistics in China Statistical Yearbook, China Energy Statistical Yearbook and China Environmental Status Bulletin, carbon emission of energy consumption is calculated as follows. If E (CO_2) is used to express carbon emission of energy consumption in the construction of China's urbanization, EC_i is the consumption of the i_{th} energy, SCC_i is the standard coal conversion coefficient of the i_{th} energy, and CEF_i is the carbon emission factor of the i_{th} energy; since the molecular weight of CO_2 is 44 and the molecular weight of carbon is 12, then the carbon emission of energy consumption can be converted into CO_2 emission according to this ratio. When K_i is the correction coefficient, if we use E (CO_2) to express per capita CO_2 emission, there is:

$$E(CO_2)_t = \sum_{t=1}^{n} \left(EC_t \cdot SCC_t \cdot CEF_t\right) \times \left(44/12\right) \tag{5}$$

The parameters in the above formula are derived from the coal conversion coefficient in the reference standards of various energy sources in the appendix of China energy statistical yearbook 2016 and the carbon emission coefficient in the IPCC national greenhouse gas inventory guide 2016. The relationship matrix of model parameters is as follows:

$$\begin{pmatrix} \text{Fuel name} & \text{Coal} & \text{Coking coal} & \text{Crude oil} & \text{Raw oil} & \text{Gasoline} & \text{Kerosene} & \text{Diesel} & \text{Natural gas} \\ SCC_i & 0.7143 & 0.9714 & 1.4286 & 1.4286 & 1.4714 & 1.4714 & 1.4571 & 1.3300 \\ CEF_i & 0.7559 & 0.8550 & 0.5538 & 0.5857 & 0.5921 & 0.5714 & 0.6185 & 0.4483 \end{pmatrix}$$

Determination and Impact Analysis of Empirical Research Data

According to the description of variable indicators in research methods, after calculating with basic data and relevant calculation formulas, the empirical basic data of the impact of China's industrialization and urbanization on carbon emission intensity of energy consumption can be determined. In order to achieve the expected research objectives and fully consider the actual situation of China's statistical data, this paper selects the relevant data of China from 1996 to 2020. The start deadline is determined as 1996, mainly because China has implemented market economy since 1996, and the end deadline is determined as 2020, because the National Bureau of statistics has not reported the statistical data of 2021. The data determination results are shown in Table 1.

In order to reflect the impact of China's industrialization and urbanization on carbon emission intensity, the histogram is used to draw the relationship between China's per capita energy consumption and per capita carbon dioxide emissions from 1996 to 2020, and the relationship and change law between these two indicators are shown in Fig. 1.

Due to the large difference between dependent variables and independent variables, in order to analyze the relationship between variables, the cumulative frequency diagram is used to reflect the cumulative relationship between variables, so as to judge the correlation between dependent variables and independent variables according to the change trend of cumulative frequency. The cumulative frequency broken line diagram of variables in Table 1 is shown in Fig. 2.

As can be seen from Fig. 2, there exists relatively good stability between variables. In order to eliminate the heteroscedasticity in the statistical data, formula (4) is used to process the above basic data, and the natural logarithm is taken with e as base. The calculation results are shown in Table 2.

In order to reflect the change trend and influence of variables, the natural logarithm of the above variables was taken, and the data of the variables after logarithm treatment were drawn in the rectangular coordinate system. It can be seen from the frequency line graph

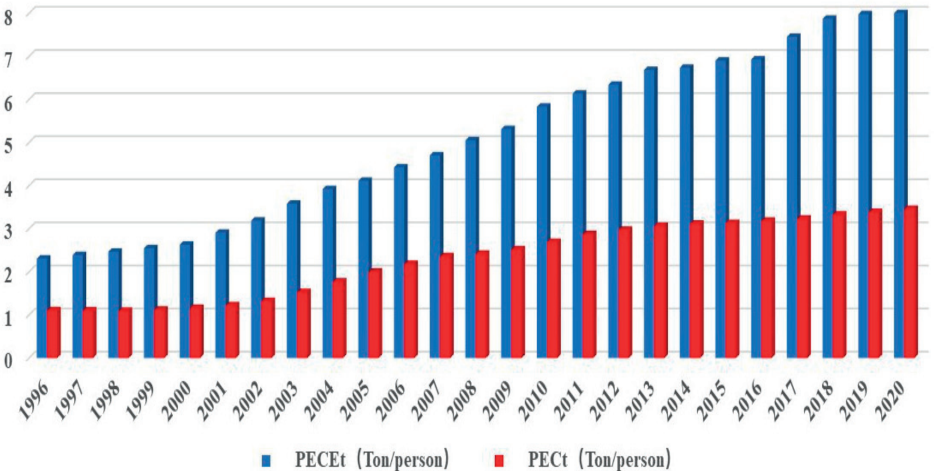

Fig. 1. Chart of the change trend of energy consumption and CO_2 emission per capita in China.

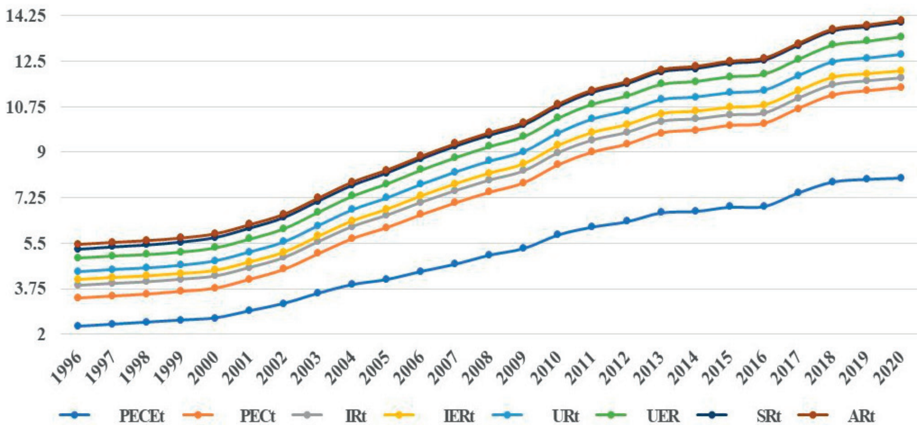

Fig. 2. Diagram of variable relationship and the variation trend.

Table 2. The logarithmic processing results of the basic data of the subject research.

Year	$lnPECE_t$	$lnPEC_t$	$lnIR_t$	$lnIER_t$	$lnUR_t$	$lnUER_t$	$lnSR_t$	$lnAR_t$
1996	0.8339	0.0995	-0.7444	-1.4473	-1.2252	-0.6274	-1.1147	-1.6246
1997	0.8688	0.0948	-0.7444	-1.4384	-1.2066	-0.6409	-1.0729	-1.6983
1998	0.9018	0.0876	-0.7722	-1.4469	-1.1907	-0.6549	-1.0161	-1.7373
1999	0.9338	0.1111	-0.7809	-1.4679	-1.1747	-0.6688	-0.9729	-1.8079
2000	0.9655	0.1480	-0.7809	-1.4894	-1.0156	-0.6846	-0.9416	-1.8839
2001	1.0661	0.1979	-0.8030	-1.5001	-0.9766	-0.6894	-0.8867	-1.9661
2002	1.1585	0.2777	-0.8097	-1.5390	-0.9393	-0.6673	-0.8627	-2.0174
2003	1.2750	0.4221	-0.7853	-1.5316	-0.9031	-0.6524	-0.8675	-2.0956
2004	1.3649	0.5719	-0.7787	-1.4899	-0.8732	-0.6296	-0.8867	-2.0479
2005	1.4127	0.6926	-0.7550	-1.4346	-0.8442	-0.6070	-0.8843	-2.1542
2006	1.4862	0.7790	-0.7423	-1.3763	-0.8233	-0.5829	-0.8723	-2.2443
2007	1.5473	0.8574	-0.7572	-1.3164	-0.7998	-0.5786	-0.8463	-2.2828
2008	1.6189	0.8814	-0.7550	-1.3009	-0.7835	-0.5720	-0.8463	-2.2828
2009	1.6692	0.9237	-0.7765	-1.2794	-0.7638	-0.5508	-0.8119	-2.3434
2010	1.7626	0.9894	-0.7657	-1.2472	-0.7444	-0.5484	-0.8164	-2.3752
2011	1.8136	1.0552	-0.7657	-1.2194	-0.6681	-0.5449	-0.8142	-2.3860
2012	1.8465	1.0885	-0.7897	-1.1920	-0.6430	-0.5425	-0.7875	-2.3969
2013	1.8992	1.1197	-0.8164	-1.2000	-0.6218	-0.5209	-0.7572	-2.4191
2014	1.9069	1.1356	-0.8416	-1.2063	-0.6020	-0.4996	-0.7277	-2.4534
2015	1.9314	1.1404	-0.8965	-1.2262	-0.5780	-0.4788	-0.6773	-2.4769
2016	1.9352	1.1577	-0.9263	-1.1632	-0.5560	-0.4742	-0.6463	-2.5133
2017	2.0082	1.1725	-0.9188	-1.2560	-0.5358	-0.4598	-0.6406	-2.5903
2018	2.0629	1.2016	-0.9238	-1.2389	-0.5179	-0.4357	-0.6292	-2.6593
2019	2.0762	1.2186	-0.9519	-1.2924	-0.5009	-0.4297	-0.6106	-2.6451
2020	2.0821	1.2401	-0.9729	-1.3292	-0.4466	-0.3786	-0.6070	-2.5639

that the relationship between variables in the empirical research has been significantly improved.

Results and Discussion

Empirical Test of Influencing Factors of Carbon Emission Intensity

(1) Variable stability test. In order to analyze the influencing factors of China's industrialization and urbanization on carbon emission of energy consumption, the stability test of variables is required to be first conducted. There are many methods to test the stability of variables. ADF and PP are selected in this paper to improve the reliability of the stability test [31]. In order to eliminate the heteroscedasticity between variables, logarithm processing has been carried out above, and the results of the stability test of variables by using EVIEWS software are shown in Table 3.

It can be seen from the above ADF and PP test results that the seven independent variables of the model all meet the requirements of stability. The above test is a first-order difference statistic test, the significance level of 5% is tested in this paper, and all variables have good stability. If the confidence of the test is changed, the test result will change accordingly. The confidence can be increased from 5% to 2.5% or 1% depending on the test accuracy requirements.

(2) Lag order test. The lag order test is a basic work of co-integration test, according to the theory of co-integration test, the selection of lag order should satisfy both the lag term of the equation and the degree of freedom of the variable to eliminate the autocorrelation of the error term of the equation [32]. After a comprehensive analysis, the lag order is selected

Table 3. Results of variable stability test of the model.

Variable	ADF test method		PP test method		Inspection result
	Test value	Probability	Test value	Probability	
Ln PEC	-0.9541	0.7648	-0.8816	0.5727	Unstable
Ln IR	-0.9828	0.8027	-0.9619	0.8116	Unstable
Ln IER	-1.1928	0.6029	-1.1726	0.5119	Unstable
Ln UR	-1.0251	0.5872	-0.9927	0.5016	Unstable
Ln UER	-1.2636	0.6951	-1.18637	0.4115	Unstable
Ln SR	-1.1739	0.6715	-1.1016	0.5025	Unstable
Ln AR	-0.8173	0.5629	0.7816	0.5618	Unstable
Δln PEC	-2.9815	0.0048	-2.8016	0.0049	Stable
Δln IR	-3.0826	0.0051	-2.9821	0.0052	Stable
Δln IER	-3.6158	0.0021	-3.5817	0.0022	Stable
Δln UR	-3.4168	0.0032	-3.3816	0.0035	Stable
Δln UER	-3.9458	0.0015	-3.8246	0.0016	Stable
Δln SR	-3.5517	0.0025	-3.4658	0.0026	Stable
Δln AR	-2.2828	0.0071	-2.26485	0.0076	Stable

as 2, and the lag period of the test is also 2. After the lag sequence test, the relationship matrix of test results is as follows:

$$\begin{pmatrix} Lag\,order & LogL & LR & FPE & AIC & SC & HQ \\ 0 & 415.3216 & & 1.23E-24 & -26.2136 & -24.2618 & -23.1629 \\ 1 & 562.1628 & 413.2617 & 2.16E-29 & -38.2167 & -35.2615 & -38.7126 \\ 2 & 742.2748 & 121.2517^{*} & 1.37E-30^{*} & -39.2814^{*} & -36.2814^{*} & -39.2618^{*} \end{pmatrix}$$

Through the above tests, it is determined that the empirical test model constructed by empirical research variables in this paper has good stability, and there is no sequential correlation between model variables, which meet the requirements of empirical test and can be used to test the co-integration of empirical model variables.

(3) Co-integration test. The co-integration test is the causality test for non-stationary sequences. The purpose of co-integration test is to determine that the equation variables have the same order characteristics. The significance of co-integration is to test whether the causal relationship described by their regression equations is a pseudo-regression, that is, to test whether there is a stable relationship between variables. According to Granger's "Co-integration Theory", the co-integration test is based on the following criteria: For n time series X_t (t = 1, 2, 3, …, n), the component of n-dimensional vector X_t is called d, b order co-integration, denoted as $X_t \sim CI(d, b)$. After determining the lag order, Johansen-Juselius co-integration test method is applied to conduct co-integration test on equation variables. The test results are shown in Table 4.

According to the results of the above co-integration test, the equation variables have the same order characteristic, which proves the validity of the empirical equation. In order to determine the parameters of the equation variables, SAS9.4 software is used to input relevant data for determination.

(4) Determination and test of equation parameters of empirical research. The equation coefficient can be determined with the test equation established above and the basic data form Table 3 by using SAS9.4, per capita carbon emission of energy consumption can also be forecast by using the determined equation, and the relationship between independent variables and dependent variables and the correlation degree can be tested. The specific equation parameters and test result matrix are as follows:

$$\begin{pmatrix} Coefficient & \beta_0 & \beta_1 & \beta_2 & \beta_3 & \beta_4 & \beta_5 & \beta_6 & \beta_7 \\ Equation\,coefficient & 1.7784 & 0.3869 & -0.2804 & -0.4048 & 1.5598 & 1.4010 & -0.6838 & -0.1228 \\ Standard\,deviation(5\%) & 1.9248 & 0.1819 & 0.7036 & 0.1956 & 0.5161 & 0.5808 & 1.0934 & 0.4029 \end{pmatrix}$$

Other parameters mainly include: T = (1995, 2016), $R^2 = 0.9982$, $\bar{R}^2 = 0.9908$, F = 126.22. According to the results in Table 8, the specific expression of the test equation can be determined, and the variable coefficient of the above equation can be substituted into formula (4) to determine the long-term equilibrium equation between each specific variable and per capita carbon emission from energy consumption:

Table 4. Results of Johansen-Juselius co-integration test.

Inspection category	Assumed co-integration number	Eigenvalue	Test statistic	5% critical value	P value
Unconstrained co-integration test	none	0.9981	286.2162	245.1526	0.0000
	At most one	0.9721	212.3715	183.2617	0.0000
	At most two	0.9426	186.1628	142.1626	0.0000
	At most three	0.9127	168.2816	137.1216	0.0000
	At most four	0.8835	129.2173	128.2617	0.0001
	At most five	0.8127	85.1251	81.2745	0.0002
	At most six	0.7821	34.1217	32.1628	0.0022
	At most seven	0.6527	12.1427	20.1217	0.0128
Maximum characteristic root co-integration test	none	0.9981	98.2618	48.2137	0.0000
	At most one	0.9721	79.1217	46.5126	0.0000
	At most two	0.9426	58.2718	44.2136	0.0000
	At most three	0.9127	42.2127	38.2813	0.0016
	At most four	0.8835	25.2716	31.2715	0.0048
	At most five	0.8127	18.2616	26.3816	0.0108
	At most six	0.7821	12.2618	20.1826	0.0216
	At most seven	0.6527	8.2716	12.8126	0.0312

$$\begin{aligned} lnPECE_t &= 1.7784 + 0.3869\,lnPEC_t - 0.2804\,lnIR_t - 0.4048\,lnIER_t + 1.5598\,lnUR_t \\ &+ 1.4010UER_t - 0.6838\,lnSR_t - 0.1228lnAR_t + \varepsilon_t \end{aligned}$$

(5) Determination of error correction model. According to the Co-integration Theory, when the equation variables are: Per capita energy consumption (PEC), Industrialization rate (IR), Industrial employment rate (IER), Urbanization rate (UR), Urban population employment rate (UER), Service industry added value rate (SR) and Agricultural industry added value rate (AR) etc. through 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_t is a cointegration vector, there are:

$$\Delta X_t = k\xi' X_{t-1} + \sum_{i=1}^{P-1} \Gamma_i \Delta X_{t-1} + \varepsilon_t \quad (t = 1,2,3,\cdots,n) \tag{6}$$

Where, $ecm_{t-1} = \xi' X_{t-1}$ is the error correction term of the test equation, which determines the size of error; k is the adjustment coefficient, which determines the adjustment speed of the influencing factors; P is the order of the equation, and i is the time-series variable, then this equation can be expressed by the error correction model:

$$\Delta X_t = \mathrm{kecm}_{\text{t-1}} + \sum_{i=1}^{\text{P-1}} \Gamma_i \Delta X_{\text{t-i}} + \varepsilon_t \tag{7}$$

According to the principle of VECM, the variables corresponding to the co-integration relation of the equation are: *Δln PEC, Δln IR, Δln IER, ΔlnUR, ΔlnUER, ΔlnSR, ΔlnAR,* the VECM of them is established to correct the error caused by the impact of independent variables variation on per capita carbon emission of energy consumption. With the original data and SAS software, and according to the determined order P = 2, the parameters of the error correction model and the test results are determined by SAS9.4, the matrix of model parameters and test results is as follows:

$$\begin{pmatrix} Coefficient & \beta_1 & \beta_2 & \beta_3 & \beta_4 & \beta_5 & \beta_6 & \beta_7 \\ Equation\,coefficient & 0.5340 & -0.3952 & -0.4438 & 1.1332 & 0.4900 & -0.5217 & -0.0981 \\ Standard\,deviation(5\%) & 0.1686 & 0.8525 & 0.2383 & 0.4602 & 0.5536 & 0.9940 & 0.3375 \end{pmatrix}$$

Other parameters mainly include: T = (1995, 2016), $R^2 = 0.9049$, $\bar{R}^2 = 0.8995$, F = 19.03. According to the modified equation test formula (6) and the determined parameters of the modified equation, the specific expression of the modified equation can be determined. The condition of the modified equation can be judged from the test results of the standard deviation and other parameters, and the error correction equation is determined as follows:

$$\Delta \ln PECE_t = 0.5340\Delta \ln PEC_t - 0.3952\Delta \ln IR_t - 0.4438\Delta \ln IER_t + 1.1332\Delta \ln UR_t$$
$$+0.4900\Delta \ln UER_t - 0.5217\Delta \ln SR_t - 0.0981\Delta \ln AR_t - 0.2215emc$$

The above modified model reflects the short-term impact of each specific influencing factor on carbon emissions per capita energy consumption. Short-term countermeasures for energy conservation and emission reduction can be put forward through short-term equilibrium analysis.

Discussion of Empirical Research Results

According to the results of the above empirical research and analyze from the long-term trend: this paper uses the theory and method of STIRPAT model, chooses per capita carbon emission from energy consumption as the dependent variable, selects seven factors as per capita energy consumption, industrialization rate, industrial employment rate, urbanization rate, urban population employment rate, service industry added value rate and agricultural value added rate as independent variables, and constructs the multivariable linear test equation of influencing factors to study the impact of China's industrialization and urbanization construction on per capita carbon emission of energy consumption. According to the results of long-term empirical test, the parameter values of the empirical test equation are shown in the radar icon, as shown in Table 3.

The study found that the selected independent variables all have a significant impact on the carbon emission intensity of per capita energy consumption, of which per capita energy consumption, urbanization rate and urban population employment rate these three independent variables have a positive impact on the carbon emission intensity of per capita energy consumption, while other variables have a negative impact on the carbon emission intensity of per capita energy consumption. According to the regression coefficient results of the cointegration equation, the influence elasticity of the seven independent variables are: 0.3869, –0.2804, –0.4048, 1.5598, 1.4010, –0.6838, –0.122. The economic implications of each influence elasticity are as follows: Every 1% increase in per capita energy consumption can increase per capita carbon emission from energy consumption by 0.3869%, indicating that China's environmental pollution control has achieved significant results. The industrial industry added value rate shows a downward trend and has a reverse change with per capita carbon emission of energy consumption, that is, every 1% decrease of industrial added value rate can increase 0.2804% per capita carbon emission of energy consumption; the industrial employment rate shows an increasing trend and is opposite to the change of per capita carbon emission from energy consumption, in other words, every 1% increase of industrial employment rate will reduce per capita carbon emission from energy consumption by 0.4048%; both the urbanization rate and the urban population employment rate show an upward trend and have the same change trend of per capita carbon emission of energy consumption, that is to say, per capita carbon emission of energy consumption will respectively increase 1.5598% and 1.4010% for every 1% increase of China's urbanization rate and urban population employment rate. The service industry added value rate shows an upward trend, which has a reverse change with the per capita carbon emission of energy consumption, that is, every 1% increase in the service industry added value rate can reduce the per capita carbon emissions of energy consumption by 0.6838%. The agricultural industry added value rate shows a downward trend, and is opposite to the change trend of per capita carbon emission of energy consumption,

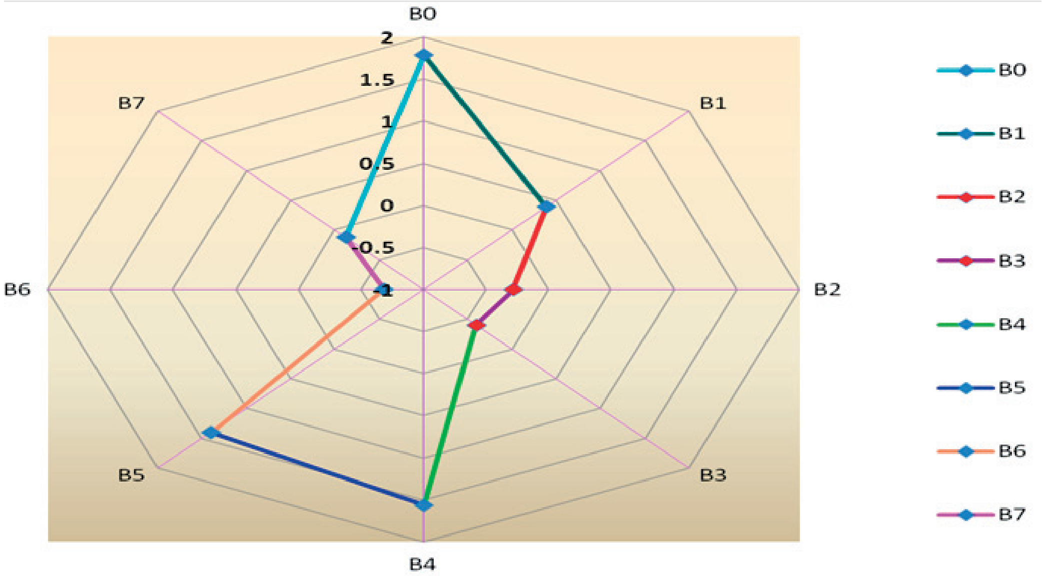

Fig. 3. Empirical test equation parameter value radar diagram.

which means every 1% decrease of agricultural industry added value rate will increase per capita carbon emission of energy consumption by 0.1228%. It can be seen that among the seven variables, the urbanization rate has the largest impact on per capita carbon emission and shows a positive impact, indicating that China's current urbanization construction lacks standardized environmental pollution protection policies and needs to be improved urgently. The urban population employment rate has the second largest impact on the carbon emission intensity of energy consumption and shows a positive impact, its influence elasticity is 1.4010, indicating that the urbanization construction in China has increased the degree of environmental degradation. The impact of other variables on the carbon emission intensity of energy consumption is listed successively below: service industry added value rate, industrial employment rate, per capita energy consumption, industrialization rate and agricultural industry added value rate.

From the test results of short-term error correction model, it can be seen that the variation of per capita carbon emission of energy consumption is basically the same as the long-term impact, urbanization development is still the main cause of per capita carbon emission of energy consumption, and the second influencing factor is per capita energy consumption. China's industrialization rate, industrial employment rate, service industry added value rate, agricultural industry added value rate and other factors all have a negative impact on carbon emission of energy consumption. With the rapid development of China's economy, per capita energy consumption shows an increase trend, while China's industrialization rate continues to decline, indicating that the development level of China's industrialization is still relatively low and has not developed into a pillar industry of social economy, which needs to be vigorously developed from both short-term and long-term analysis. From the coefficient and test results, it can be seen that the equilibrium of positive impact and negative impact is mainly caused by the error adjustment term ecm_{t-1}, which adjusts the unbalanced state of per capita carbon emission of energy consumption back to the equilibrium state at a speed of 0.2215.

Conclusion

In order to explore effective ways to reduce the per capita carbon emissions of energy consumption in China, on the basis of literature review and situation analysis, through in-depth analysis of STIRPAT model and give full consideration to the actual situation of the actual carbon emission of energy consumption in China, this paper chooses seven independent variables related to China's industrialization and urbanization and constructs the extended STIRPAT model of per capita carbon emissions of energy consumption. On the basis of relevant tests, the extended STIRPAT model was used to test the long-term impact of selected independent variables on energy consumption carbon emission intensity, and the error correction equation was used to test the short-term impact of each influencing factor on the energy consumption and carbon emission intensity. The study found that the main factor affecting China's per capita carbon emissions of energy consumption is the urbanization construction; China's industrialization level has a negative impact on per capita carbon emissions of energy consumption, indicating that China's industrialization level is still relatively low and is not the main factor affecting per capita carbon emission. The service industry added value rate has a negative impact on the per capita carbon emission of energy consumption, which means the increase of this rate can promote the decrease of per capita carbon emission of energy consumption. However, the excessive service industry added value rate will restrict the development of the secondary and primary industries and is not conducive to the long-term development of China's economy. Based on the above research results, the following aspects of policy recommendations are proposed：

(1) Gradually accelerate the pace of China's industrialization and appropriately control the development speed of service industry. The current industrialization level of China is relatively low. The industrial added value rate in 2020 is only 37.80%. The service industry has become the largest contributor to GDP and in 2020, the added value of the service industry accounts for 54.50% of GDP. This may lead to a lack of sustainable momentum for China's economic development. Therefore, from the perspective of long-term development requirements, it is urgent to improve the degree of industrialization in China. To accelerate the pace of China's industrialization under the background of the "dual carbon" goal, it is important to consider the impact of environmental regulations and use green financial means to promote the process of low-carbon industry, so as to avoid the simultaneous increase of the industrialization process and the carbon emission intensity of energy consumption.

(2) Appropriately control the speed of urbanization and moderately develop agriculture. From the research results of this paper, it can be seen that both long-term and short-term urbanization development are main reasons for per capita carbon emissions of energy consumption. Controlling the speed of urbanization construction and focusing on improving construction quality have become an important issue to be solved urgently. China was once a big agricultural country, but the lagging development of agriculture has greatly affected the overall development of China's economy. So, increasing the speed of agricultural development is also conducive to reducing the intensity of carbon emissions.

(3) Keeping per capita energy consumption under control is an important way for energy conservation and emission reduction. In the long run, China's per capita

energy consumption has been controlled and is no longer the main factor affecting carbon emissions per capita energy consumption; in the short run, controlling per capita energy consumption is still an important way to control per capita carbon emissions, and the green transformation of China's economy must start in the short term.

Acknowledgments

This paper is supported by the humanities and Social Sciences Foundation of the Ministry of Education, the project number is 19YJA790098. The author thanks the humanities and Social Sciences Foundation of the Ministry of Education of China for providing research funds for this research, at the same time, I would like to thank the National Bureau of statistics of China for providing the relevant data required for this study.

Conflict of Interest

The authors declare no conflict of interest.

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