A Study on the Influencing Factors of Carbon Emissions in Provincial Construction Industry Based on LMDI Model–Taking Shandong Province as an Example

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Abstract This paper takes the construction industry in Shandong Province as the research object and calculates the CO_2 emissions of the construction industry in Shandong Province for 15 years from 2005 to 2019 by using the IPCC carbon emission factor method, and analyzes the factors influencing the carbon emissions of the construction industry in Shandong Province from five aspects, such as carbon emission intensity, energy consumption structure, energy intensity, economic level, and population scale, by Logarithmic mean Divisia index (LMDI) decomposition method. The analysis result indicates that energy intensity and economic level are the critical factors influencing the change in carbon emission in Shandong Province's construction industry. Among them, the economic level is the major factor that promotes the positive growth of carbon emissions in Shandong Province's construction industry, with a contribution rate of 2329.39% of the total effect; energy intensity is an important factor that suppresses carbon emissions in Shandong Province's construction industry, with a contribution rate of −2739.81%.

Keywords Construction industry in Shandong Province · Carbon emission · LMDI model · Impact factor

1 Introduction

With the development of economic globalization, climate warming and environmental pollution have become issues of concern all over the world, and the high emission of CO_2 is the root cause of these problems. According to the latest data released by the International Energy Agency (IEA), the global energy sector CO_2 emissions in 2021 set a new history-breaking record, rising by 6% compared to 2020,

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with a total of 36.3 billion tons. Among them, China's CO_2 emissions exceed 11.9 billion tons, accounting for 33% of global CO_2 emissions [1]. At the 75th United Nations Conference held on September 22, 2020, General Secretary Xi Jinping put forward the "carbon peaking and carbon neutrality" goals, which are to strive to peak China's CO_2 emissions by 2030, and achieve "carbon neutrality" by 2060 [2]. The construction industry, as one of the three major sectors of global energy consumption and CO_2 emissions, will largely determine whether China will achieve "carbon neutrality" by 2060.

As a strong economic province and a large population province, Shandong Province, the gross value of the construction industry has been increasing year by year, and the total construction output value of the province reached 149.4730 billion CNY by 2020, a year-on-year increase of 4.75%. However, with the steady and rapid development of the construction economy, the energy consumption and greenhouse gas emissions of the construction industry in Shandong Province are also increasing. According to the latest data released by the National Bureau of Statistics, the total energy consumption of Shandong Province is as high as 423.9 million tons of standard coal, the first in the country, and the total emissions of major pollutants 193.3 million tons, ranking third in the country. In this regard, under the condition of stable economic growth, it is of great significance to study and analyze the carbon emission of the construction industry in Shandong province and identify the factors that affect the carbon emission of the construction industry scientifically and effectively to solve the ecological environment problems in Shandong province and achieve the goal of "carbon neutrality".

2 Literature Review

In recent years, as the importance of the construction industry in the field of energy-saving and emission reduction has been highlighted, the factors influencing carbon emission in the construction industry have become a research hotspot for scholars at home and abroad. However, most of the studies have been gathered from the macro perspective, and only a few scholars have focused on the study of carbon emission impact factors in specific regions.

The research scope of carbon emission influencing factors is divided into two categories: national and local. Shan decomposed the influencing factors of carbon emission changes in China from 2000–2017 based on Kaya's constant equation and LMDI model, and regressed them using the STIRPAT model [3]; Li decomposed the driving factors of carbon emission in China from 2001–2016 based on LMDI method, and obtained the structural effect, technological effect, economic effect[4]; Liu et al. used the STIRPAT model to quantitatively analyze the carbon emission impact factors of public and residential buildings in Guangzhou from 2006–2014 [5]; Jiang et al. focused on the study of the impact factors of the construction industry in Jiangsu Province, and used the LMDI model to decompose the carbon emission changes of the construction industry in Jiangsu Province from 2011–2017 [6]. A review of a large amount of relevant literature reveals that domestic research on the influencing factors of carbon emissions in the construction industry is mainly focused on the national level, but there is still a lot of research space to extend to specific provinces, except for Gansu [7] and Liaoning [8] where the research is relatively well developed. In addition, the current research on the influencing factors of carbon emissions in Shandong Province mainly focuses on the transportation industry [9], coal industry [10], agriculture [11] and other fields, and the research involving the construction industry is still insufficient.

Although scholars abroad and at home have studied the factors influencing carbon emissions in the construction industry, most of the studies are at the national macro level, the provincial studies are not mature, and the studies focusing on the construction industry in Shandong Province are still a vacancy. Therefore, this article takes the construction industry in Shandong Province as the starting point, and decomposes the carbon emissions of the construction industry in Shandong Province from 2005 to 2019 based on the LMDI decomposition method, to explore the focus of energy saving and emission reduction in the construction industry in Shandong Province, and provide a practical reference for China to achieve the goal of "carbon peaking and carbon neutrality".

3 Analysis of Current Situation

As shown in Table 1, the overall energy consumption of the construction industry in Shandong Province shows a fluctuating trend, and the energy consumption in the four years from 2005 to 2008 was basically flat; In the four years from 2009 to 2011, the construction industry in Shandong Province was in a time of high-speed development, and the consumption of traditional energy sources such as coal and diesel reached a new high, peaking at 7.896 million tons of standard coal in 2011; after the 18th National Congress of the Communist Party of China, Shandong Province has stepped up efforts in energy conservation and environmental protection, so the energy consumption has fallen off a cliff in 2013–2014, although energy consumption has grown after 2016, there is still a big gap with the peak (Fig. 1). From the perspective of the proportion of energy consumption, the overall trend is more obvious. Except for the increase in the proportion in 2008, the proportion of energy consumption in the construction industry in Shandong Province showed a downward trend in the whole country, and in 2019 compared with 2005, it decreased by 10.69% (Fig. 2).

Table 1 The energy consumptions ratio of the construction industry in Shandong Province from 2005 to 2019

Year	Total energy consumption in Shandong Province	Total energy consumption of The construction industry in China	Proportion (%)
2005	556.2	3486	15.96
2006	547.8	3836	14.28
2007	554.0	4203	13.18
2008	563.0	3874	14.53
2009	665.0	4712	14.11
2010	725.8	5533	13.12
2011	789.6	6052	13.05
2012	715.6	6337	11.29
2013	755.4	7017	10.77
2014	470.2	7377	6.37
2015	416.4	7545	5.52
2016	426.8	7847	5.44
2017	430.0	8243	5.22
2018	437.3	8685	5.04
2019	481.4	9142	5.27

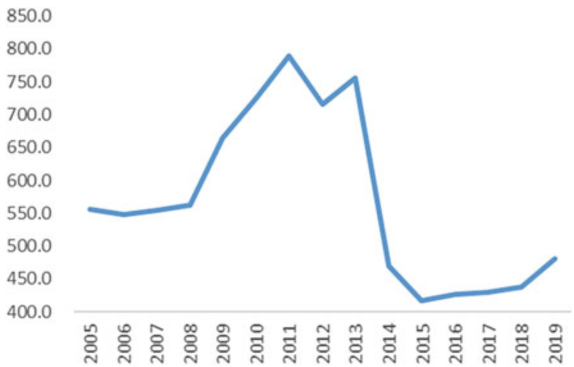

Fig. 1 Total energy consumption of the construction industry in Shandong Province from 2005 to 2019

4 Methodology

4.1 IPCC Carbon Emission Measurement Model

This paper uses the IPCC emission coefficient method to measure the carbon emissions of the construction industry in Shandong Province, which was proposed in the first "Guidelines for National Greenhouse Gas Inventories" issued by IPCC in 1996. Because of its simple, easy-to-understand, and high practicability, it is widely used to

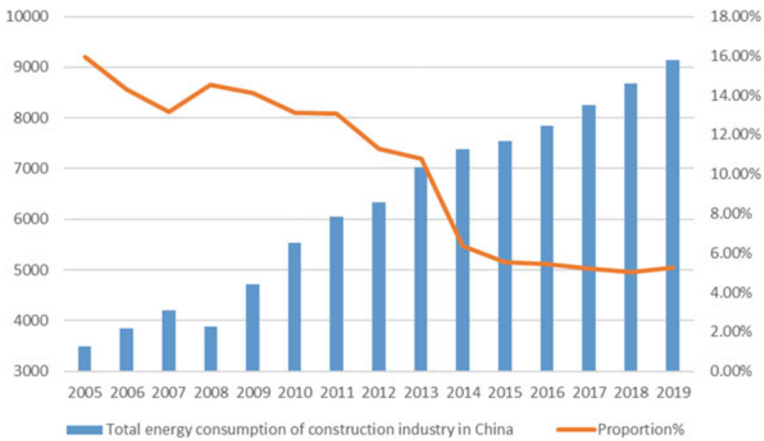

Fig. 2 Proportion of building energy consumption in Shandong Province from 2005 to 2019

calculate building carbon emissions [12]. The following models are used to measure the carbon emissions of buildings.

$$N = \sum_i C_i \times \alpha_i \tag{1}$$

$$C_i = c_i \times \beta_i \tag{2}$$

In formula (1), N represents the total amount of carbon emissions from buildings; C_i represents the consumption of various energy sources after converting to standard coal (10,000 tons); α_i represents the carbon emission coefficient of various energy sources (t carbon/t standard coal)). In formula (2), c_i represents the consumption of various energy sources before conversion (10,000 tons); β_i represents the standard coal coefficient of various energy conversions.

4.2 Decomposition Models

The LMDI decomposition method was proposed by Ang [13], which has the characteristics of adequate decomposition, ease to use, and wide range of use, and its biggest advantage is that it does not produce residual problems and allows the data to contain zero values. Therefore, the article adopts the "summation decomposition" form of the LMDI decomposition method to quantitatively analyze the factors influencing carbon emissions in the construction industry of Shandong Province, which combines the LMDI decomposition model with Kaya's constant equation proposed by Yoichi Kaya at the IPCC workshop, which relates CO_2 emissions to energy, economy, and population with the following equation.

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{P} \times P \tag{3}$$

In the article, the kaya constant is further extended to five influencing factors with the following equation.

$$E = \sum_i E_i = \sum_i \frac{E_i}{F_i} \times \frac{F_i}{Z} \times \frac{Z}{G} \times \frac{G}{P} \times P \tag{4}$$

In formula (4), E represents the total amount of carbon emissions from buildings in Shandong Province; i represents the type of energy (1–9 represent raw coal, coking coal, gasoline, kerosene, diesel, fuel oil, liquid petroleum gas, natural gas, and electricity, respectively); E_i represents the carbon emissions of the energy (10,000 tons); F_i represents the energy consumption (10,000 tons of standard coal); Z represents the total energy consumption of Shandong's construction industry (10,000 tons of standard coal); G Indicates the total production value of the construction industry in Shandong Province (100 million CNY); P represents the total population of Shandong Province (10,000 people).

In order to facilitate the calculation, let B $= \frac{E_i}{F_i}$ represent the carbon emission intensity of the energy source, that is, the carbon emission coefficient;

D $= \frac{i}{Z}$ represents the proportion of the energy consumption, that is, the energy consumption structure;

K $= \frac{Z}{G}$ represents the energy consumption per unit of construction GDP in Shandong Province, that is, energy intensity;

L $= \frac{G}{P}$ means GDP per capita, that is, the economic level;

So formula (4) can be written as

$$\mathrm{E} = \mathrm{K} \times \mathrm{L} \times \sum (B_i \times D_i) \times P \tag{5}$$

From formula (5), the article decomposes the influencing factors of carbon emission in the construction industry of Shandong province into 5 factors: carbon emission intensity, energy intensity, energy consumption structure, economic level, and population size.

Then the LMDI index method is used to decompose the carbon emission factors in Shandong Province, and the above five individual impact indicators are used to quantitatively analyze the degree of impact through the "additive form".

$$\begin{aligned} \Delta \mathrm{E} = E_t - E_0 &= \frac{E_t - E_0}{lnE_t - lnE_0} \times (lnE_t - lnE_0) \\ &= \Delta E_B + \Delta E_D + \Delta E_K + \Delta E_L + \Delta E_P \end{aligned} \tag{6}$$

ΔE represents the change in the target year T CO_2 emissions compared to the base year 0, ΔE_B, ΔE_P, ΔE_D, ΔE_K, ΔE_L represent the carbon emission coefficient factor, energy consumption structure factor, energy intensity factor, economic level factor, population size factor, and the formula for calculating the contribution value of each impact factor are:

$$\Delta E_B = \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \ln\left(\frac{B_{iT}}{B_{i0}}\right) \tag{7}$$

$$\Delta E_D = \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \ln(\frac{D_{iT}}{D_{i0}}) \tag{8}$$

$$\Delta E_K = \ln\left(\frac{K_T}{K_0}\right) \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \tag{9}$$

$$\Delta E_L = \ln\left(\frac{L_T}{L_0}\right) \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \tag{10}$$

$$\Delta E_P = \ln\left(\frac{P_T}{P_0}\right) \sum_i \frac{E_{iT} - E_{i0}}{lnC_{iT} - lnC_{i0}} \tag{11}$$

Because the carbon emission coefficients of various building energy sources are fixed values, ΔE_B is 0, so the final calculation formula is as follows:

$$\Delta \mathrm{E} = E_t - E_0 = \Delta E_D + \Delta E_K + \Delta E_L + \Delta E_P \tag{12}$$

5 Results and Discussion

Based on the LMDI decomposition model, according to formulas (4)–(12), it can be obtained that the energy consumption structure effect E_D, the energy intensity effect E_K, the economic level effect E_L of the construction industry, and the population scale effect E_P in each stage from 2005 to 2019 the construction sector in Shandong Province Contribution to carbon emissions (Table 2).

5.1 Overall Effect

As shown in Table 2, if the contribution rate is >0, it means that the impact factor has a promoting effect on the positive change of carbon emissions, that is, the increase; if the contribution rate is less than 0, it means that the impact factor has an inhibitory effect on the increase of carbon emissions.

It can be seen that from 2005 to 2019, the overall carbon emissions of the construction industry in Shandong Province increased by 283,100 tons, with an average annual

Table 2 LMDI decomposition results of CO_2 emission change in the Shandong construction industry

	ΔEd	ΔEk	ΔEl	ΔEp	ΔE
2005–2006	26.03	−36.10	29.65	1.95	21.52
2006–2007	−11.00	−58.65	60.59	2.39	−6.67
2007–2008	−53.75	−48.73	52.50	1.86	−48.11
2008–2009	6.58	−3.28	62.78	2.08	68.15
2009–2010	−2.75	−40.12	72.20	4.83	34.16
2010–2011	6.29	−37.31	72.10	4.13	45.21
2011–2012	−31.19	−93.35	48.60	1.93	−74.00
2012–2013	−8.15	−38.81	58.93	1.57	13.54
2013–2014	228.59	−247.84	38.69	2.76	22.20
2014–2015	41.13	−56.57	0.47	2.60	−12.37
2015–2016	−2.84	−21.02	27.07	4.70	7.92
2016–2017	−3.19	−51.65	52.28	2.55	−0.01
2017–2018	−65.98	−40.32	45.35	1.77	−59.18
2018–2019	−21.50	−1.92	38.27	1.12	15.97
Average	7.73	−55.40	47.11	2.59	2.02
Total	108.29	−775.67	659.47	36.22	28.31
Contribution rate (%)	382.50	−2739.81	2329.39	127.92	100.00

increase of 20,200 tons. Among them, only the impact factor of energy intensity has an inhibitory effect on the increase of carbon emissions, which reduces the overall carbon emissions by 775.67 tons, an average annual reduction of 554,000 tons, and the contribution rate is as high as −2739.81%.

The other three influencing factors—poor energy consumption structure, improved economic level, and population growth—have contributed to the increase in carbon emissions, resulting in an overall increase of 8,039,800 tons of carbon emissions, with an average annual increase of 574,300 tons. In detail, the contributions of these three factors are far from each other: the economic level factor leads to an increase of 6,594,700 tons of carbon emissions, accounting for 2,329.39% of the total effect, becoming the main factor promoting the increase in carbon emissions; energy consumption structure The factor promotes an increase of 1.0829 million tons of carbon emissions, accounting for 382.50% of the total effect. The population scale factor leads to an increase of 362,200 tons of carbon emissions, an average annual increase of 25,900 tons, and the lowest contribution is only 9.32%.

5.2 The Effect of Energy Consumption Structure

According to formula (8), the specific energy consumption structure contribution value of various energy sources is calculated (Table 3). From Table 3, it can be seen that the overall effect of the energy consumption structure from 2005 to 2019 led to an increase of 1.0829 million tons of carbon emissions from the construction industry in Shandong Province. Among them, coke, kerosene, diesel, fuel oil, natural gas, and electricity are the positive factors for the increase of carbon emissions in the construction industry, and raw coal, gasoline, and liquefied gas are the negative factors for the increase of carbon emissions. It can be seen from Fig. 3 that diesel and raw coal have relatively prominent effects on the increase and decrease of carbon emissions, but their effects on the direction of carbon emissions change are positive and negative, and the contributions of the two are basically offset. Therefore, the impact of the energy consumption structure effect on the changes in carbon emissions of the construction industry in Shandong Province is not obvious.

5.3 The Effect of Energy Intensity

According to formula (9), the specific energy intensity contribution values of various energy sources are calculated (Table 4). From Table 4, it can be seen that from 2005 to 2019, the energy intensity effect inhibited the positive growth of carbon emissions from the construction industry in Shandong Province, and the overall reduction was 7.7567 million tons. It can be clearly seen from Fig. 4 that the energy intensity data in Shandong are all negative values, which further indicates that the energy intensity effect promotes the negative change in carbon emissions in the construction industry, but the change is not in a linear form, but fluctuates in stages. For example, the inhibitory effect of energy intensity on carbon emission reduction in 2012–2013 was smaller than that in the previous year, and the energy intensity in 2013–2014 had the largest inhibitory effect on carbon emissions in the construction industry in 15 years. The main reason for this phenomenon is that during the 10 years from 2003 to 2012, the economic construction of Shandong Province has developed vigorously, and energy consumption has entered the fastest growing stage. In 2012, the total energy consumption of Shandong Province was as high as 337.901 million tons of standard coal, ranking first in the country [14]. Since 2013, Shandong Province has implemented the concept of "Clear waters and green mountains are as good as mountains of gold and silver", the growth momentum of coal consumption has gradually slowed down, and the growth rate of energy consumption in the province has dropped significantly. Overall, the energy intensity effect is the most important factor restraining the growth of carbon emissions from the construction industry in Shandong Province.

Table 3 Calculation results of energy structure effect from 2005 to 2019

	Raw coal	Coke	Petrol	Kerosene	Diesel oil	Fuel oil	Liquid gas	Natural gas	Electricity	Total
2005–2006	2.66	0	0	0	21.45	0	0.98	0	0.94	26.03
2006–2007	−4.21	0	−0.1	0	1.75	0	−9.14	0	0.71	−11
2007–2008	29.94	0	−29.55	0.36	−71.32	11.6	3.56	0.08	1.59	−53.75
2008–2009	−11.34	0	2.67	0	16.31	−1.06	−0.01	0.01	−0.01	6.58
2009–2010	−9.18	0	0.58	0	4.99	−0.49	0.04	0	1.31	−2.75
2010–2011	−1.37	0	−1.76	0.01	8.1	−0.24	0.07	0.02	1.46	6.29
2011–2012	−31.11	0	−43.65	−0.4	56.77	−14.09	−1.74	0	3.03	−31.19
2012–2013	−63.46	0.64	31.22	1.12	4.14	17.12	0.3	0.04	0.73	−8.15
2013–2014	17.14	1.34	34.56	0.64	152.52	8.73	2.16	0.12	11.39	228.59
2014–2015	−0.97	−0.02	4.56	0	35.02	0.99	−0.66	0	2.22	41.13
2015–2016	−1.77	−1.31	0.32	−0.16	1.48	−0.27	−2.82	0.05	1.65	−2.84
2016–2017	−14.24	0	2.45	0.26	6.8	0	0	0.02	1.51	−3.19
2017–2018	−11.77	0	−18.3	23.66	−58.95	−3.42	0.43	−0.03	2.41	−65.98
2018–2019	−1.63	0	−4.27	−3.04	−14.09	−1.12	0.06	0.03	2.56	−21.5
Total	−101.3	0.65	−21.28	22.45	164.97	17.74	−6.76	0.33	31.49	108.29

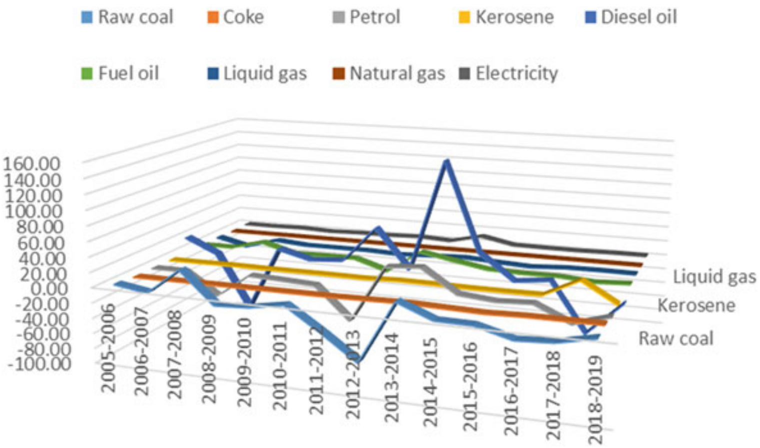

Fig. 3 A 2005–2019 energy consumption structure effect

5.4 The Effect of Economic Level

From Table 2, it can be seen that from 2005 to 2019, the economic horizontal structural effect has promoted a total of 6.5947 million tons of carbon emissions from the construction industry in Shandong Province. It can be seen from Fig. 5 that the contribution value of the economic level effect is all greater than 0, but the effect of this effect on the positive change of carbon emissions in the construction industry also fluctuates irregularly. Among them, the years with large fluctuations were 2005–2006, 2008–2009, 2014–2015,and 2015–2016; the effect of economic level effect on carbon emission reduction in 2013–2015 decreased year by year, and the contribution value as of 2015 reach the minimum is 0.47 million tons. Nevertheless, the economic level effect is still the main factor driving the growth of carbon emissions from the construction industry in Shandong.

5.5 The Effect of Population Size

The population scale effect is directly dependent on population growth. Table 2 visually shows that the population of Shandong Province increased from 92.48 million to 101.06 million from 2005 to 2019, the population scale effect increased the carbon emissions of the construction industry in Shandong Province by 362,200 tons, proving that carbon emissions The amount will increase as the population increases. It can be seen from Fig. 6 that, compared with other influencing factors, the effect of population size on the positive change of carbon emissions in the construction industry is relatively stable, with small changes, and a relatively low contribution rate.

Table 4 Calculation results of energy intensity effect from 2005 to 2019

	Raw coal	Coke	Petrol	Kerosene	Diesel oil	Fuel oil	Liquid gas	Natural gas	Electricity	Total
2005–2006	−10.41	0.00	0.00	0.00	−23.67	0.00	−1.06	0.00	−0.96	−36.10
2006–2007	−12.89	0.00	−13.07	0.00	−31.37	0.00	0.00	0.00	−1.32	−58.65
2007–2008	−13.62	0.00	−9.89	0.00	−23.83	0.00	0.00	0.00	−1.38	−48.73
2008–2009	−1.05	0.00	−0.57	0.00	−1.42	−0.11	−0.03	0.00	−0.10	−3.28
2009–2010	−11.75	0.00	−7.09	0.00	−18.31	−1.22	−0.42	0.00	−1.33	−40.12
2010–2011	−10.42	0.00	−6.51	−0.03	−17.49	−1.10	−0.39	−0.01	−1.35	−37.31
2011–2012	−23.92	0.00	−11.80	0.00	−52.76	0.00	−0.85	0.00	−4.02	−93.35
2012–2013	−5.45	0.00	−4.75	0.00	−26.32	0.00	−0.31	−0.01	−1.96	−38.81
2013–2014	−18.36	−0.57	−39.23	−0.66	−164.56	−9.89	−2.09	−0.11	−12.36	−247.84
2014–2015	−3.95	−0.18	−8.73	−0.15	−38.08	−2.19	−0.43	−0.02	−2.83	−56.57
2015–2016	−1.35	0.00	−3.24	−0.05	−14.47	−0.80	0.00	−0.01	−1.10	−21.02
2016–2017	−2.37	0.00	−8.47	−0.13	−37.63	0.00	0.00	−0.03	−3.02	−51.65
2017–2018	−0.56	0.00	−6.20	−0.78	−28.55	−1.50	0.00	−0.02	−2.71	−40.32
2018–2019	0.00	0.00	−0.27	−0.12	−1.31	−0.07	0.00	0.00	−0.15	−1.92
Total	−116.10	−0.75	−119.82	−1.92	−479.77	−16.88	−5.58	−0.23	−34.62	−775.67

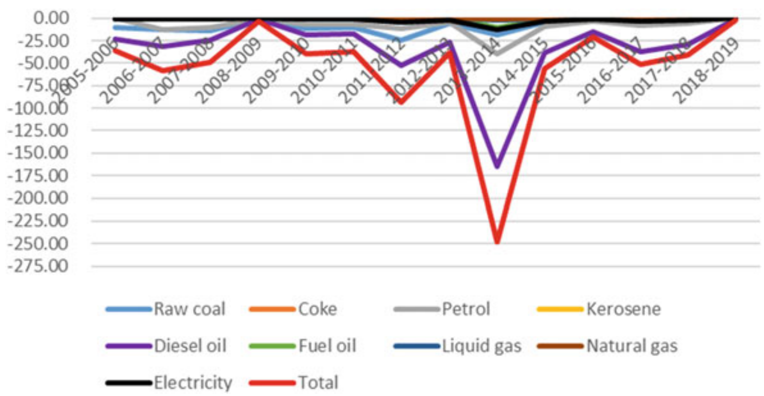

Fig. 4 The effect of energy efficiency on carbon emissions of the construction industry in Shandong Province from 2005 to 2019

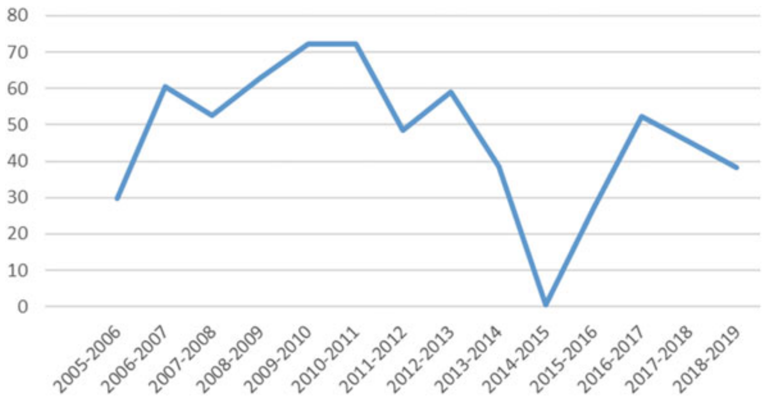

Fig. 5 The effect of economic level on carbon emissions of the construction industry in Shandong Province from 2005 to 2019

6 Conclusion

This paper uses the LMDI decomposition method to decompose the factors affecting the carbon emissions of the construction industry in Shandong Province, and draws the following conclusions:

Energy consumption structure, economic level and population size are the driving factors for the increase in carbon emissions from the construction industry in Shandong. Among them, the economic level is the key factor to promote the positive increase of carbon emissions in the construction industry in Shandong, and its contribution value is as high as 6.5947 million tons, with a contribution rate of 2329.39%; the contribution of energy consumption structure to carbon emissions ranks second, with a contribution rate of 382.50%; The population size factor has the least driving

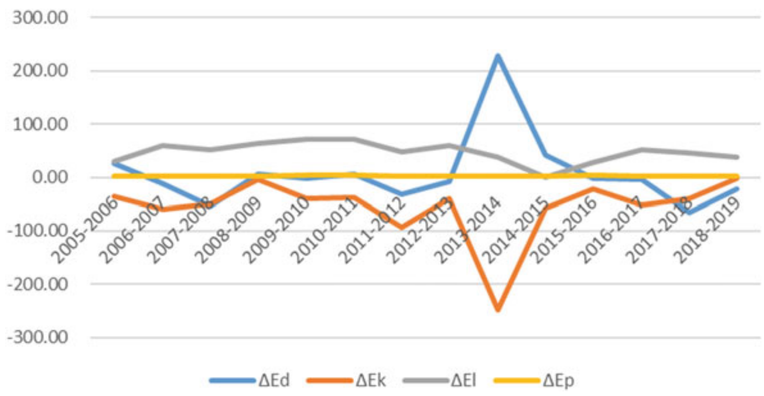

Fig. 6 The effect of various influencing factors on the carbon emissions of the construction industry in Shandong Province from 2005 to 2019

effect on the growth of carbon emissions, with a contribution value of only 362,200 tons, accounting for 127.92% of the total effect; (2) Energy intensity is the most important factor in restraining carbon emissions from the construction industry in Shandong. From 2005 to 2019, with the improvement of energy utilization rate and the advancement of energy conservation and emission reduction technologies, the energy intensity continued to decrease, and the macroscopically promoted carbon emission reduction of 7.7567 million tons, with a contribution rate of 2739.81%.

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