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Article

Carbon Emissions Decomposition and Environmental Mitigation Policy Recommendations for Sustainable Development in Shandong Province

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Abstract: Provincial carbon emissions research is necessary for China to realize emissions reduction targets. Two-level decomposition model based on the Kaya identity was applied to uncover the main driving forces for the energy related carbon emissions in Shandong province from 1995 to 2011, an important energy base in China. Coal consumption is still the biggest contributor to the increased carbon emissions in Shandong. Decomposition results show that the affluence effect is the most important contributors to the carbon emissions increments. The energy intensity effect is the dominant factor in curbing carbon emissions. The emission coefficient effect plays an important negative but relatively minor effect on carbon emissions. Based on the local realities, a series of environment-friendly mitigation policies are raised by fully considering all of these influencing factors. Sustainable mitigation policies will pay more attention to the low-carbon economic development along with the significant energy intensity reduction in Shangdong province.

Keywords: carbon emissions; environmental mitigation policy; logarithmic mean Divisia index (LMDI); Shandong province

1. Introduction

Global climate change has posed an imminent threat to the existence of humans and all other living beings. Carbon emissions from fossil fuel combustion are the main contributor to anthropogenic global change [1,2]. Under such circumstances, the international community has paid great attention to the environmental impacts associated with fossil energy use. Curbing greenhouse gas emissions has become a priority in developing strategies for a sustainable future, raising the awareness of policy makers and government managers around the whole world [3–5]. China, the biggest developing country, has become the world's top energy consumer and CO_2 emitter after several decades of rapid economic growth [6–8]. Therefore, an increasing number of studies have been conducted by researchers inside and outside the country to uncover the main driving forces for the increasing carbon emissions in China. Wang *et al.* conducted the logarithmic mean Divisia index (LMDI) method to analyze the change of aggregated CO_2 emissions in China from 1957 to 2000 [9]. Wu *et al.* [10] paid special attention to the stagnancy of China's carbon emissions from 1996 to 1999 by using the LMDI method. Zhang *et al.* extended the time series from 1991 to 2006 for China's carbon emissions decomposition [11,12]. Economic activities were confirmed as the most important contributors to China's increased carbon emissions, while the efforts of energy efficiency was highlighted for curbing carbon emissions. Therefore Liao *et al.* decomposed China's industrial energy intensity changes during 1997 to 2002 [13]. Zhao *et al.* [14] conducted the index decomposition analysis to identify the key forces behind the rapid increase in China's energy intensity from 1998 to 2006. As a result, China has achieved a considerable decrease in carbon emissions, mainly due to improved energy efficiency [15,16], fossil fuel substitution [17,18], industrial structure optimization [10,13], and technology improvements [19].

In particular, there are pronounced differences in development model, economic structure, consumption levels, available technology, residential lifestyles, and resource endowment across the different provinces within China [20,21]. A country's carbon emissions assessment should not only focus on changes in the total amount, but also focus on changes in the regional pattern. Therefore, there is an urgent need to have a deeper understanding on the national experience-based learning as well as provincial case-based empirical studies to inform itself of the best route to low-carbon sustainability.

Shandong province, an important energy base in China, is located in the eastern coast of China in the lower reaches of the Yellow River (Figure 1). At the end of 2011, its gross domestic product (GDP) was 4536.19 billion Yuan (in current prices), 9.59% of China's total GDP. The total population was 96.37 million, 7.15% of China's total population. In the "Twelfth Five-Year Plan" period (2010 to 2015), Shandong has promised that carbon emissions per unit of GDP would have an absolute decline in the background of "energy conservation and emissions reduction". Economic growth will be constrained by environment and resources constantly. Aims of this case study are to analyze the energy related carbon emissions and recommend environmental mitigation policy. In the next section, we present the method to decompose the changes in carbon emissions and carbon emissions intensity during the whole research period. Section 3 addresses the data source and calculates the primary energy related carbon emissions. Section 4 presents the case analysis of Shandong province. The main results and discussion are reported in Section 5. Finally, we conclude our study and provide some policy implications.

Figure 1. Location of Shandong Province in China.

2. Methodology

2.1. Analysis along Kaya Factors

The Kaya identity expresses the carbon emissions (C) as a product of four driving factors [22–24]:

$$C = P \times \left(\frac{G}{P}\right) \times \left(\frac{E}{G}\right) \times \left(\frac{C}{E}\right) = pgef \tag{1}$$

where P is the population, G is gross domestic product (GDP), E is primary energy consumption; $g = G/P$ is the per-capita GDP, $e = E/G$ is the energy intensity of GDP (energy intensity) and $f = C/E$ is the carbon emission coefficient of energy. The time series of GDP is taken in constant 1990 prices to avoid the impact of inflation.

2.2. Decomposition of Carbon Emissions

A lot of decomposition analysis approaches are available in the open literature over time. Two kinds of decomposition techniques, namely the structural decomposition analysis (SDA), which is based on the input-output tables and the index decomposition analysis (IDA), which uses aggregate data, have been developed independently and widely applied to analyze the driving forces [12,18,25]. Data requirements lead to fundamental differences between SDA and IDA [25]. SDA model is based on the input-output model framework, which presents decompositions in quantitative economics on the sector scale [26]. Therefore, time series I-O tables and sector energy consumption data should be collected for the SDA method [27–29]. SDA uses information from I-O tables, while IDA uses aggregate data at the sector level [30]. IDA can be applied readily to any available data at any level of aggregation in a period-wise or time-series manner [11,12,17]. LMDI method was introduced and refined by Ang [31–34], which was known as the ideal Divisia index decomposition method in IDA. Since then, it has been widely used in IDA researches. In our case study, LMDI method—estimating each individual effect through formulations in terms of the weighted average logarithmic changes of the relevant variables, was chosen, owing to its leaving no residuals in the analysis.

From Equation (1), using the LMDI method refined by Ang, difference in the emission levels between two years can be further decomposed as:

$$\Delta C = C_t - C_0 = \Delta C_{p-effect} + \Delta C_{g-effect} + \Delta C_{e-effect} + \Delta C_{f-effect} \tag{2}$$

where ΔC is the change of carbon emissions between a base year 0 and a target year t, which can be further decomposed to four effects as follows: changes in the population effect ($\Delta C_{p-effect}$), changes in the affluence effect ($\Delta C_{g-effect}$), changes in the energy intensity of GDP effect ($\Delta C_{e-effect}$) and changes in the emission coefficient effect ($\Delta C_{f-effect}$).

$$\Delta C_{p-effect} = \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln(\frac{p_t}{p_0}) \tag{3}$$

$$\Delta C_{g-effect} = \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln(\frac{g_t}{g_0}) \tag{4}$$

$$\Delta C_{e-effect} = \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln(\frac{e_t}{e_0}) \tag{5}$$

$$\Delta C_{f-effect} = \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln(\frac{f_t}{f_0}) \tag{6}$$

2.3. Decomposition of Energy Intensity

In order to further explore the factors affecting the energy intensity of GDP, our study conducted LMDI decomposition on the energy intensity using the following decomposition formula:

$$I = \frac{E}{GDP} = \frac{\sum_j E_j}{\sum_j GDP_j} = \sum_j \frac{E_j}{GDP_j} \times \frac{GDP_j}{\sum GDP_j} = \sum_j e_j \times s_j \tag{7}$$

Energy intensity was examined by the index decomposition method introduced by Choi and Ang [35,36] in our study. Where e_j is the energy intensity of the j th sector, s_j is the economic share of the j th sector.

$$\begin{aligned}\Delta I = I_t - I_0 = \Delta I_{e-primary} + \Delta I_{e-industry} + \Delta I_{e-construction} + \Delta I_{e-tertiary} \\ + \Delta I_{s-primary} + \Delta I_{s-industry} + \Delta I_{s-construction} + \Delta I_{s-tertiary}\end{aligned} \tag{8}$$

$$\Delta I_{e_j} = \frac{W_{j,t} - W_{j,0}}{\ln W_{j,t} - \ln W_{j,0}} \ln(\frac{e_{j,t}}{e_{j,0}}) \quad (9)$$

$$\Delta I_{s_j} = \frac{W_{j,t} - W_{j,0}}{\ln W_{j,t} - \ln W_{j,0}} \ln(\frac{s_{j,t}}{s_{j,0}}) \quad (10)$$

$$W_j = e_j \times s_j \quad (11)$$

ΔI is change in energy intensity between year 0 and year t, $\Delta I_{e-primary}$, $\Delta I_{e-industry}$, $\Delta I_{e-construction}$ and $\Delta I_{e-tertiary}$ are changes in energy intensity of primary ($EI_{primary}$), industry ($EI_{industry}$), construction ($EI_{construction}$) and tertiary ($EI_{tertiary}$), respectively. $\Delta I_{s-primary}$, $\Delta I_{s-industry}$, $\Delta I_{s-construction}$ and $\Delta I_{s-tertiary}$ are industrial structure change effect of primary industries ($SE_{primary}$), industry ($SE_{industry}$), construction ($SE_{construction}$) and tertiary ($SE_{tertiary}$). In our study, primary industries include agriculture, forestry, animal husbandry and fishery. Industry and construction constitute secondary industries. All other industries are tertiary industries.

3. Data Management

Data resources, include population, gross domestic product (GDP) and total primary energy consumption from 1995 to 2011, were collected from various issues of Shandong Statistical Yearbook (SSY, 1995–2012), China Statistical Yearbook (CSY, 1995–2012) and China Energy Statistical Yearbook (CESY, 1995–2012). The GDP data is in 10^8 Yuan in constant 1990 prices. The energy related data is in 10,000 tons of coal equivalent (10,000 tce) in calorific value calculation. Carbon emissions were calculated based on the overall energy balance sheet of Shandong province in main years.

Energy related carbon emissions were calculated according to the IPCC guidelines for national greenhouse gas inventories in 2006 [11,12,15].

$$C_t = \sum_i E_t^i \times LCV_i \times CF_t^i \times O_i \quad (12)$$

where the subscript i represents the various fuels including coal, oil and natural gas in our study, t is the time in years, C_t is total carbon emissions in year t (in million tons, Mt), E_t^i is the total energy consumption of the fuel type i in year t (million tons of standard coal equivalent, Mtce); LCV_i is the lower calorific value of fuel i. CF_t^i is the carbon emissions factors of the fuel type i. O_i is the oxidation rate of fuel i. The conversion factors and carbon emission factors of energy sources are listed in Table 1.

Table 1. Conversion factors, LCV, oxidation rate and carbon emission factors of energy sources.

Energy sources	Conversion factors [a]	LCV (MJ/t or MJ/Mm^3) [b]	Carbon emission factors (t C/TJ) [c]	Oxidation rate [c]
Raw coal	0.7143 tce/t	20.908	25.80	0.918
Cleaned coal	0.9000 tce/t	26.344	27.68	0.918
Coke	0.9714 tce/t	28.435	29.41	0.928
Crude oil	1.4286 tce/t	41.816	20.08	0.979
Gasoline	1.4714 tce/t	43.070	18.90	0.986
Kerosene	1.4714 tce/t	43.070	19.60	0.980

Table 1. *Cont.*

Energy sources	Conversion factors [a]	LCV (MJ/t or MJ/Mm^3) [b]	Carbon emission factors (t C/TJ) [c]	Oxidation rate [c]
Diesel oil	1.4571 tce/t	42.652	20.17	0.982
Nature gas	1.33tce/10^{3}m^3	38.931	17.20	0.990
Refinery gas	1.5714 tce/t	46.055	18.20	0.989
LPG	1.7143 tce/t	50.179	17.20	0.989

Notes: [a] Data resources: [37]; [b] Data resources: [38,39]; [c] Data resources: [39].

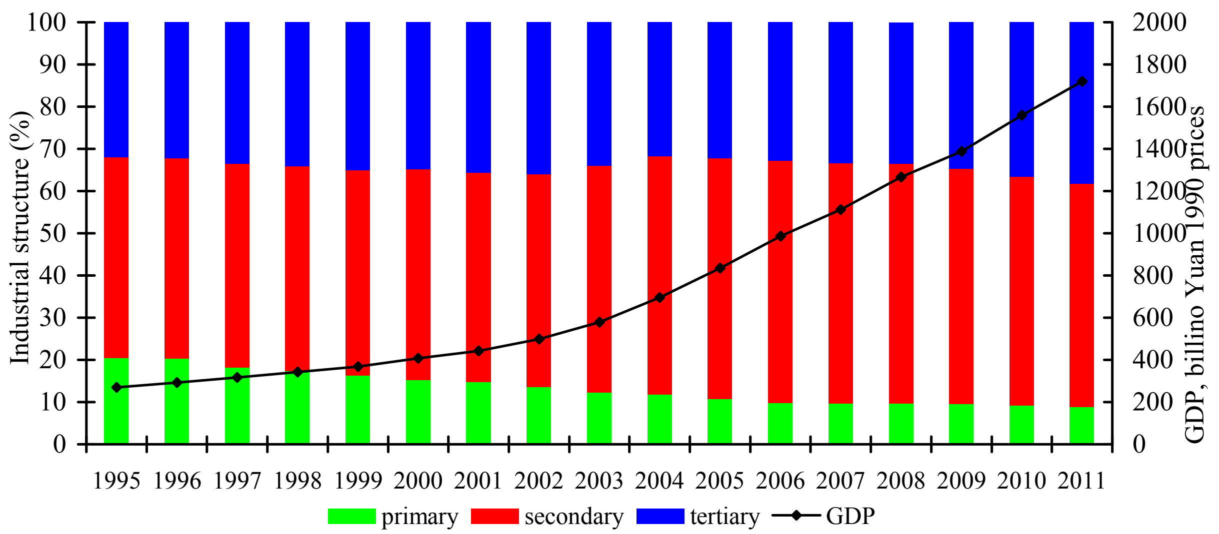
4. Case Analysis in Shandong Province

Based on the methods mentioned above, we presented the case analysis of Shandong province from 1995 to 2011.

4.1. Economic Development and Industrial Structure Change

GDP of Shandong has increased from 270.38 billion Yuan in 1995 to 1718.99 billion Yuan in 2011 in constant 1990 prices (Figure 2), growing by 11.49% per year. Changes of industrial structure from 1995 to 2011 in Shandong province were also shown in Figure 2. There is an obvious decrease in the shares of primary industries, from 20.39% in 1995 to 8.76% in 2011. On the contrary, there is an increase in the secondary industries, from 47.56% in 1995 to 52.95% in 2011. The proportion of the tertiary industries grew slightly, from 32.05% in 1995 to 38.29% in 2011. It indicates that Shandong province was a dominant industrial economy during the research period, but the tertiary sector grew faster than the secondary one.

Figure 2. Economic development and industrial structure changes in Shandong province (1995–2011).



4.2. Energy Consumption and Carbon Emissions

Figure 3 shows the evolution of the primary energy consumption structure in Shandong province during 1995–2011. Coal share in the primary energy consumption decreased slightly, from 78.45% in

1995 to 76.47% in 2011. The proportion of oil increased slowly from 19.38% in 1995 to 21.62% in 2011. Natural gas has a very small proportion in the total primary energy consumption, less than 2%. It illustrates that coal has a leading role in the energy mix.

With rapid economic growth, total primary energy consumption increased from 99.38 million tce in 1995 to 385.07 million tce in 2011, performing an annual growth rate of 8.29%. Total carbon emissions increased markedly, 286.12% over the period 1995 to 2011, and coal consumption is the biggest contributor to the total carbon emissions (Figure 4). Carbon emissions from coal, oil and natural gas in 1995 were 56.43 million tons, 11.28 million tons, and 0.97 million tons, respectively. Then to 2011, carbon emissions from coal, oil and natural gas consumption were 213.11 million tons, 48.76 million tons, and 3.29 million tons, respectively.

Figure 3. Changes in the energy consumption structure in Shandong province (1995–2011).

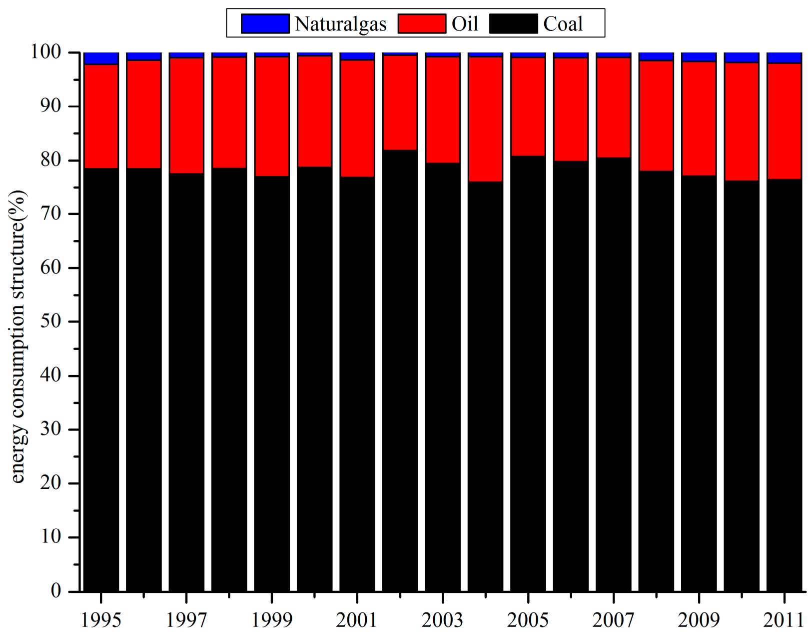
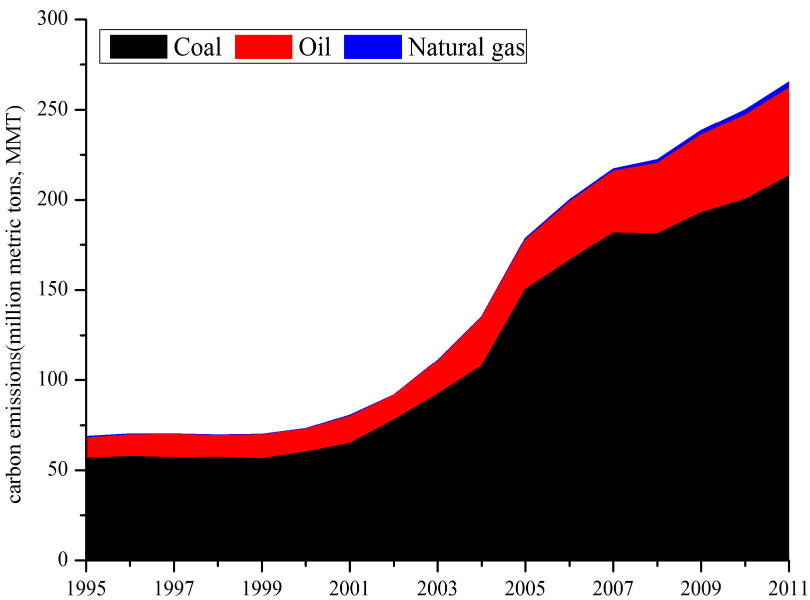


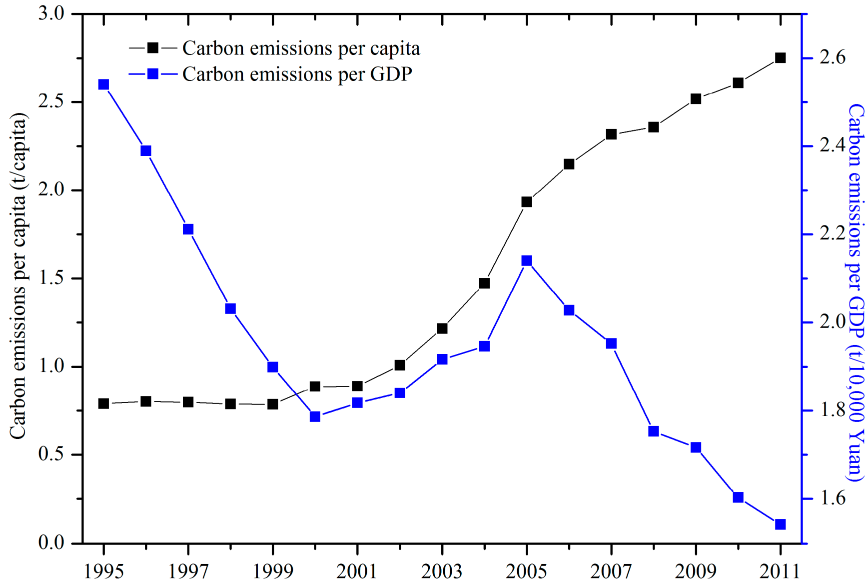
Figure 4. Total primary energy consumption carbon emissions in Shandong province (1995–2011).



4.3. Carbon Emissions per Capita and Carbon Emissions Intensity

Figure 5 shows that carbon emission per capita increased from 0.79 tons per capita in 1995 to 2.75 tons per capita in 2011, a rapid growth trend was performed after 2000. In general, carbon emissions per GDP (1990 prices) decreased from 2.54 t/10,000 Yuan in 1995 to 1.54 t/10,000 Yuan in 2011, but it exhibited a complex change trend. It decreased at 1.79 t/10,000 Yuan until 2000, then it increased at 2.14 t/10,000 Yuan until 2005, and after that date it reduced continuously.

Figure 5. Changes in carbon emissions per capita and carbon emissions per GDP in Shandong province from 1995 to 2011.



5. Results and Discussion

We then used the method, LMDI based on Kaya identity, presented in section 2 to decompose carbon emissions yearly from 1995 to 2011.

5.1. Decomposition of Carbon Emissions

Table 2 presents the decomposition results of carbon emissions in Shandong province from 1995 to 2011. Economic activity was the most important factor; population scale was the next most important driving force for the carbon emissions increase from 1995 to 2011. Especially, economic activity was the biggest contributor, bringing about 254.23 million tons increase, which accounts for 129.39% of the total change (ΔC) in absolute value. In addition, 14.79 million tons carbon emissions increase was attributable to population growth, which accounts for 7.53% of the total change (ΔC) in absolute value.

At the same time, the energy intensity effect (*e-effect*) played a most important role in curbing carbon emissions growth, resulting in a 72.03 million tons decrease, accounting for 36.66% of the total changes (ΔC) in absolute value. Although the energy intensity effect obvious fluctuated, it was the most negative effect. We found that the total carbon emissions increased 105.85 million tons from the special period 2000 to 2005, which accounts for 53.87% of the total change (ΔC) from 1995 to 2011. Furthermore, energy intensity decreased from 3.68 tce/10,000 Yuan in 1995 to 2.57 tce/10,000 Yuan in 2000, and then increased to 3.08 tce/10,000 Yuan in 2005, finally decreased to 2.24 tce/10,000 Yuan in 2011. It clearly illustrates that the decline or increase of energy intensity, to a great extent, restrained or accelerated the growth rate of total carbon emissions.

The emission coefficient effect was the least important factor and only resulted in a 0.50 million tons decrease from 1995 to 2011, which accounts for only 0.25% of the total change (*ΔC*) in absolute value. Although the share of coal in the primary energy consumption decreased from 78.45% in 1995 to 76.47% in 2011, energy structure adjustment has posed a slight influence on carbon emissions during the research period. Fortunately, emission coefficient effect played a relatively minor, but important, negative effect on carbon emissions.

Table 2. Complete decomposition of the changes in carbon emissions in millions of tons in Shandong province (1995–2011).

	p-effect	*g-effect*	*e-effect*	*f-effect*	*ΔC*
1995–1996	0.26	5.31	−4.34	0.11	1.35
1996–1997	0.38	5.07	−5.37	−0.07	0.01
1997–1998	0.42	4.97	−6.08	0.15	−0.54
1998–1999	0.35	4.66	−4.49	−0.20	0.32
1999–2000	0.91	6.56	−4.64	0.28	3.10
2000–2001	0.37	5.75	1.74	−0.41	7.46
2001–2002	0.39	9.77	0.06	1.00	11.22
2002–2003	0.48	14.72	4.66	−0.53	19.32
2003–2004	0.74	21.69	2.70	−0.85	24.27
2004–2005	1.15	27.56	13.43	1.43	43.57
2005–2006	1.24	30.15	−9.86	−0.38	21.16
2006–2007	1.29	23.67	−8.22	0.31	17.05
2007–2008	1.17	27.52	−22.30	−1.33	5.05
2008–2009	1.29	19.75	−4.33	−0.46	16.25
2009–2010	2.79	25.50	−16.13	−0.58	11.58
2010–2011	1.55	23.65	−10.00	0.10	15.30
1995–2011	14.79	254.23	−72.03	−0.50	196.49

In addition, there was an interesting finding that carbon emissions from primary energy consumption increased only 0.01 million tons from 1996 to 1997. Energy consumption even decreased from 101.29 million tce in 1997 to 100.29 million tce in 1998. We deduced that the "Asian financial crisis" in 1997 affected the economic development in Shandong. Slow economic growth made foreign trade exports suffer a heavy blow, and foreign demands for commodities were decreased, especially mechanical products, building materials, *etc.*, exporting from Shandong to Southeast Asia markets. All these potential factors led to the weak energy consumption demands along with the slow economic growth.

5.2. Decomposition of Carbon Emissions Intensity

The energy intensity effect (*e-effect*) played a most important role in curbing carbon emissions growth, indicating that examination of this factor should be further carried out. Extended Divisia index decomposition of changes in energy intensity introduced by Choi and Ang [35,36] was adopted in our study (Equations (7)–(11)) to perform residual-free decomposition. But the accurate and successive energy consumption data series at the industrial level were only from 2005 to 2011, our results were mainly focused on this period.

Figure 6 shows the development of industrial energy intensity in Shandong province from 2005 to 2011. Industry energy intensity was higher than other three sectors, which is 13.15−, 5.05−, and 3.37 fold that of primary industries, construction, and tertiary industries, respectively, in 2011. But all four sectors' energy intensity presented declining trends. Especially energy intensity of industry decreased from 4.48 tce/10,000 Yuan in 2005 to 3.48 tce/10,000 Yuan in 2011.

Figure 6. Industrial energy intensity changes in Shandong province (2005–2011).

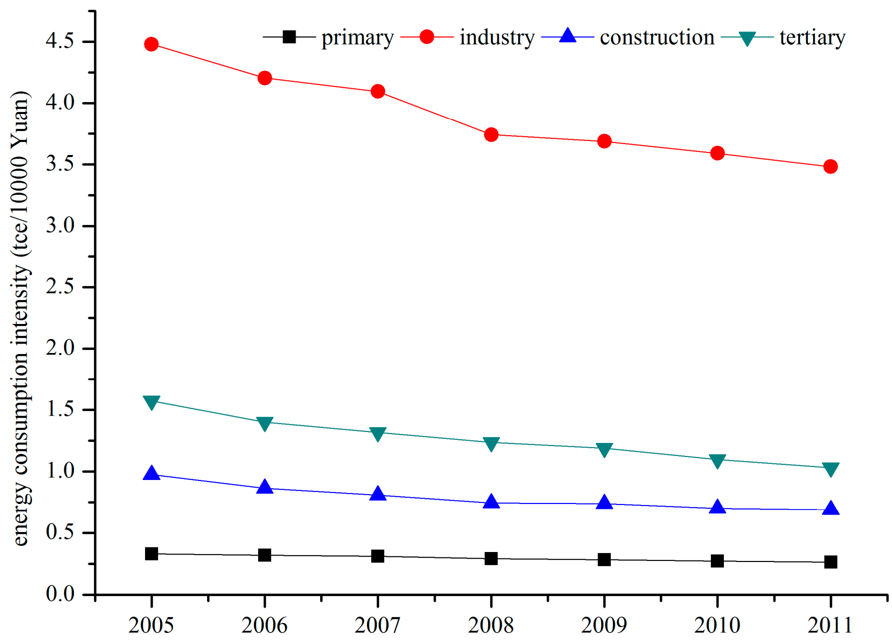


Table 3 presented the complete decomposition results of the energy intensity changes in Shandong province from 2005 to 2011. $ECI_{industry}$ and $SCE_{industry}$ were the dominant factors affecting energy intensity. $ECI_{industry}$ and $SCE_{industry}$ produced 0.4907 tce/10,000 Yuan decrease and 0.1737 tce/10,000 Yuan decrease from 2005 to 2011, respectively, which account for 61.05% and 21.61% of the total change (Δe) in absolute value. The share of industry in the economic structure increased from 43.97% in 2000 to 51.28% in 2005, and then decreased to 48.15% in 2010. Industry plays a dominant role in Shandong's economic development. Because the «11th Five-year Plan» in Shandong province (2006–2010) explicitly pointed out that Shandong province should make full use of comparative advantages, focus on the construction of manufacturing sectors during 2006 to 2010, especially mechanical equipment industry, chemical engineering industry, material industry, *etc.* All these governmental policies made Shandong's heavy industrialization characteristics significantly. The share of heavy industry in the total industrial output value increased from 62.91% in 2005 to 68.83% in 2011. $ECI_{primary}$ and $SCE_{primary}$ played a very minor role in decreasing energy intensity, which account for 0.79% and 0.71% of the total change (Δe) in absolute value especially during the period 2005 to 2011. The effect of $ECI_{tertiary}$ decreased energy intensity year by year, with a 0.1897 tce/10,000 Yuan decrease from 2005 to 2011, accounting for 23.59% of the total change (Δe) in absolute value. On the contrary, effect of $SCE_{tertiary}$

increased energy intensity from 2005 to 2011. We can see that intensity effects all played important roles in decreasing the total energy intensity after 2005, but this phenomenon was not seen in structural effects. Local governmental policies played an important influence on energy consumption in Shandong. The adjustment of structure has reduction effects on carbon emissions, but the inhibitory effect is not obvious, economic structure has yet to be optimized in Shandong province. Fortunately, the «12th Five-year Plan» in Shandong province (2011–2015) clearly pointed out that Shandong would optimize industrial structure and enhance enterprises' technical level (energy conservation and emission reduction), especially focus on renewable energy industry, new material industry, energy saving and environmental protection industry, *etc.* All these new governmental policies will offer us green hope in the coming years.

Table 3. Complete decomposition of the energy intensity changes in Shandong province (2005–2011).

	ECI_1	ECI_2	ECI_3	ECI_4	SCE_1	SCE_2	SCE_3	SCE_4	Δe
2005–2006	−0.0011	−0.1418	−0.0063	−0.0568	−0.0030	0.0294	−0.0029	0.0083	−0.1742
2006–2007	−0.0008	−0.0569	−0.0029	−0.0269	−0.0001	−0.0176	−0.0014	0.0085	−0.0981
2007–2008	−0.0018	−0.1819	−0.0035	−0.0268	−0.0001	−0.0058	0.0010	0.0006	−0.2184
2008–2009	−0.0008	−0.0275	−0.0004	−0.0167	−0.0005	−0.0572	0.0037	0.0149	−0.0845
2009–2010	−0.0011	−0.0474	−0.0022	−0.0327	−0.0010	−0.0616	0.0011	0.0217	−0.1233
2010–2011	−0.0007	−0.0519	−0.0007	−0.0244	−0.0011	−0.0442	−0.0002	0.0178	−0.1054
2005–2011	−0.0064	−0.4907	−0.0169	−0.1897	−0.0057	−0.1737	0.0022	0.0770	−0.8038

Notes: ECI_1, ECI_2, ECI_3, ECI_4 are intensity effects of primary industries ($ECI_{primary}$), industry ($ECI_{industry}$), construction ($ECI_{construction}$) and tertiary ($ECI_{tertiary}$), respectively. SCE_1, SCE_2, SCE_3, SCE_4 are structural effects of primary industries ($SCE_{primary}$), industry ($SCE_{industry}$), construction ($SCE_{construction}$) and tertiary ($SCE_{tertiary}$).

6. Conclusions and Discussions

In our study, we used the Logarithmic Mean Divisia Index (LMDI) method to analyze the primary energy consumption related carbon emissions in Shandong province during the period 1995 to 2011. The four decomposition factors are population growth, economic activity, energy intensity, and energy carbon intensity. Furthermore, we used this decomposition method to analyze the important factor of energy intensity during period 2005 to 2011. The main conclusions are presented as follows:

Shandong province is a coal dominant industrial economy. Industry plays a dominant role in the economic development in Shandong province, which is featured by heavy industrialization. Coal consumption is the biggest contributor to carbon emissions. The total carbon emissions increased markedly, 286.12% over the period 1995 to 2011.

Economic activity was the most important factor, population growth was the next most important factor in driving carbon emissions increase, bringing about 254.23 MMT and 14.79 MMT carbon emissions increase over the period 1995 to 2011, respectively. However the energy intensity effect fluctuated obviously; it was the most important factor in conducting carbon emissions decline, resulted in 72.03 MMT carbon emissions decrease, which accounts for 36.66% of the total change (***ΔCE***) in absolute value during the entire research period. Furthermore, the decline or increase of energy intensity to a great extent restrained or accelerated the growth rate of total carbon emissions. Energy carbon intensity was the least important factor, only resulted in a decrease of 0.50 MMT carbon emissions from 1995 to 2011, which accounts for only 0.25% of the total change ($\boldsymbol{\Delta CE}$) in absolute value, but energy carbon intensity has revealed a important role in depressing carbon emissions growth.

The coal-dominated energy structure did not undergo a fundamental change, inhibitory effects on carbon emissions produced by the energy efficiency and energy structure can't overcome the carbon emissions increase driving by the rapidly economic development in Shandong province. $ECI_{industry}$ and $SCE_{industry}$ played a dominant role in affecting the energy intensity. The adjustment of structure has reduction effect on carbon emissions, but the inhibitory effect is not obvious, economic structure has yet to be optimized in Shandong province. Local governmental policies played an important influence on energy consumption in Shandong. We expect that some new governmental policies will offer us green hope in the coming years.

Shandong province should continue to carry out the "Target Responsibility Mechanism" and introduce the implementation of incentive policies at the same time. Government should establish the related independent agency with authorities and high sense of responsibility to supervise the implementation of these policies, and then know how to adjust these policies. We expect that these policies proposed by us will play important roles in the economic and social development and carbon emissions mitigation.

7. Policy Implications

Based on our above research results, Strategies and policies (Figure 7) for developing low carbon economy in Shandong province will be fully talked about from now on.

(1) Economic policy: It is necessary to maintain steady economic growth and increase investment in renewable energy and energy technology. All efforts should be made to improve macroeconomic control abilities and implement carbon emissions mitigation, realizing coordinated development between economy and environment.

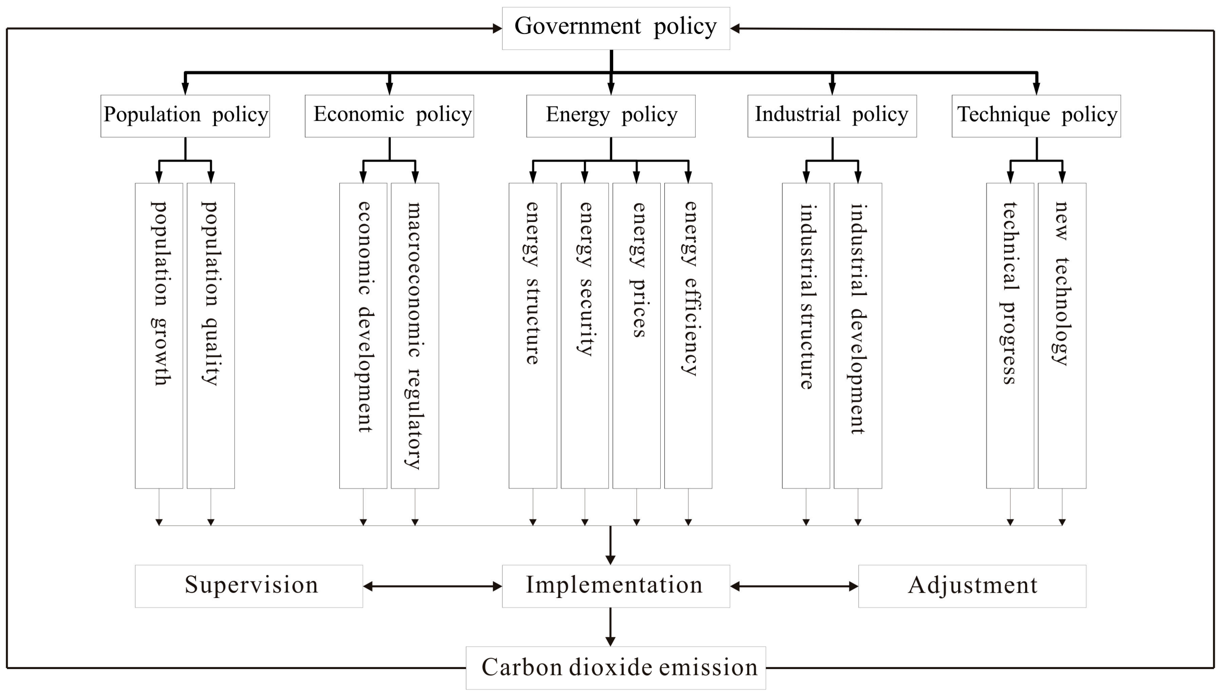
(2) Population policy: Shandong province should continue to control population growth and improve population quality in the future. Population quality improvement emerged in people's "low-carbon and environmental protection" concepts and is becoming popular. Government should lead low carbon consumption activities, especially choosing public transportation.

(3) Energy policy: The share of coal in the primary energy consumption and its dominant energy carrier position can't change in the near future. But a number of energy policies should be implemented to increase energy efficiency and optimize energy structure. Renewable low-carbon energy resources, such as solar energy, ocean energy, and wind energy, *etc.* should be paid more attention, and especially nuclear energy. Energy prices should be reasonable, in order to protect energy supply and demands from enterprise and individual consumers. Energy security is emphasized for nuclear energy [5], especially the Shidaowan HTGR nuclear power demonstration project with the world's first IV-Generation technology. Efficiency and safety must be given priority to the implement of energy policies. All these energy policies are aiming at continuous energy structure optimization.

(4) Industrial policy: In the future, Shandong province should continue to ensure industrial development and try to change the heavy industrialization trend effectively. Government should pay attention to nurture the emerging low-carbon industries, especially focus on the renewable energy industry, new material industry, energy saving and environmental protection industry, *etc.*, in order to highlight the inhibitory effect of industrial structure optimization on carbon emissions growth.

(5) Technology policy: The effects of industrial energy intensity all played an important role in decreasing the total energy intensity after 2005. That is because Shandong province made the energy consumption per unit of GDP an assessment indicator in the each industrial sector and the various enterprises after the «11th Five-year Plan» in Shandong province (2006–2010) and supervised the implementation of related policies strictly, namely the "Target Responsibility Mechanism". Shandong province should take all kinds of technical measures to improve energy efficiency, such as exploiting new energy-saving products, using new technology, adopting low-carbon building, and developing low-carbon transport system, *etc.*

Figure 7. Diagram of the interaction of Carbon emissions impact factors.



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Author Contributions

Changjian Wang, Fei Wang and Hongou Zhang designed research; Changjian Wang, Fei Wang, Hongou Zhang and Yuyao Ye performed research, Changjian Wang, Hongou Zhang, Qitao Wu and Yongxian Su contributed new analytic tools; All authors wrote the paper. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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