

CO₂ emissions from industrial sector in Fujian Province, China: A decomposition analysis

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Abstract. Industries of Fujian Province use more energy than any other sectors and it is important to explore both the characteristics and reduction potential of their CO₂ emissions. A decomposition analysis based on the LMDI method during 2005-2016 is performed to investigate the main driving forces behind energy-related CO₂ emissions variations in Fujian Province, China. We find that raw coal, crude oil and electricity are ranked in the top three CO₂ emissions. The proportion of CO₂ emissions from raw coal still accounts for the largest proportion of CO₂ emissions from all types of energy. The total CO₂ emissions of industrial energy consumption increased from 44.27 million tons (Mt) in 2005 to 88.51 Mt in 2016. The industrial scale effect is the main driving factor for the growth of CO₂ emissions in Fujian industry sector. The energy intensity effect is the main inhibitor of the growth of CO₂ emissions. The energy structure effect has only a weak positive or negative impact on Fujian industrial CO₂ emissions. Finally, some potential policy implications are put forward on mitigating carbon emissions.

1. Introduction

There is already growing evidence of an increase in greenhouse gas (GHG) concentrations in the atmosphere contributing to global climate warming. The main source of CO₂ emissions—the most important GHG—has been the increasing fossil-fuel use and other human activities. The CO₂ concentration, now standing at about 400 ppm, is expected to reach 450 ppm by 2030, and is estimated to be a concentration between 540 ppm and 970 ppm over the next century [1, 2]. Besides the global temperature rise of 0.85 °C in the past 130 years, CO₂ emissions also reflect a large quantity of environmental issues, such as the heat-transfer conductance of urban areas and fog and haze [3, 4].

With the economy growing, China has become the biggest carbon emitter in 2013 [5]. Accompanying by rapid industrialization and urbanization, Chinese energy consumption has sharply increased and the proportion of energy consumption in the industrial sector still accounts for more than 80%. Hence, policies, measures and researches on the energy crisis and CO₂ emissions control are focused primarily on the industrial sector. However, in order to put forward effective policies and measures to reduce CO₂ emissions from industrial sector, it is necessary to understand trends and factors affecting these emissions. The factors responsible for changes in the energy-related CO₂ emissions mainly are: (i) abatement technologies; (ii) the structure and efficiency of the energy systems; (iii) economic progress and (iv) the total economic activity [6].



In this paper, a decomposition analysis based on the LMDI method covering the years from 2005 to 2016 is performed to investigate the main driving forces behind energy-related CO₂ emissions variations in Fujian Province, China. Some potential strategies are suggested to promote mitigating energy-related carbon emissions. The analysis can provide relevant policy guidance to enact statutes for energy savings and emissions reduction in Fujian Province.

2. Methods and data

2.1. Calculation of CO₂ emissions

The energy-related CO₂ emissions of Fujian are estimated based on 2006 IPCC Guidelines, which can be expressed as follows:

$$C = \sum_{i=1}^n E_i \times f_i \quad (1)$$

Where C refers to the total CO₂ emissions, E_i refers to the amount of energy i used, and f_i refers to the CO₂ emission coefficient of energy source i .

2.2. LMDI method

In this study, LMDI is used to decompose the influencing factors of energy-related CO₂ emissions in Fujian. Energy-related CO₂ emissions can be decomposed as follows:

$$C_t = \sum_i C_{it} = \sum_i \frac{C_{it}}{E_{it}} \times \frac{E_{it}}{E_t} \times \frac{E_t}{Q_t} \times Q_t = \sum_i e_{it} \times r_{it} \times s_t \times g_t \quad (2)$$

Where C_t is the total CO₂ emissions of various types of energy in year t ; i denotes the i -th energy source; C_{it} the CO₂ emissions amount of energy source i ; E_{it} the consumption of energy source i ; E_t is the total consumption of various types of energy in year t ; Q_t is the industrial output value in year t .

Consequently, the total emissions in year t can be disaggregated into four factors: the energy emission intensity (e_{it}); the energy consumption structure (r_{it}); the energy consumption intensity (s_t) and industrial output (g_t). Thus, the change in total CO₂ emissions (ΔC_{tot}) between the base period (C_t) and target period (C_{t+1}) can be written as:

$$\Delta C_{tot} = C_{t+1} - C_t = \Delta C_{ei} + \Delta C_{ri} + \Delta C_s + \Delta C_g \quad (3)$$

Since the CO₂ emissions coefficient of each energy source remains basically unchanged, the energy emission intensity effect $\Delta C_{ei}=0$. Therefore, the total emissions can be decomposed into the following effects based on the LMDI method [7].

$$\Delta C_{ri} = \sum_i \frac{C_{i,t+1} - C_{i,t}}{\ln C_{i,t+1} - \ln C_{i,t}} \times \ln \frac{r_{i,t+1}}{r_{i,t}} \quad (4)$$

$$\Delta C_s = \sum_i \frac{C_{i,t+1} - C_{i,t}}{\ln C_{i,t+1} - \ln C_{i,t}} \times \ln \frac{s_{t+1}}{s_t} \quad (5)$$

$$\Delta C_g = \sum_i \frac{C_{i,t+1} - C_{i,t}}{\ln C_{i,t+1} - \ln C_{i,t}} \times \ln \frac{g_{t+1}}{g_t} \quad (6)$$

2.3. Data source

The data used for the decomposition analysis comes from China Energy Statistical Yearbook and Fujian Statistical Yearbook covering the years from 2005 to 2016. Specifically, we used the following data: energy balance of Fujian (Physical Quantity) and industrial output value per year. Data including consumption of various types of energy and gross industrial output value.

According to the characteristics of industrial energy consumption in Fujian, nine major types of energy such as raw coal, crude oil and natural gas are selected for analysis, and all types of energy consumption are converted into standard coal using reference coefficient. The carbon emissions coefficient is determined by the data from China Energy Statistical Yearbook and the 2006 IPCC Guidelines. The reference coefficient of converting different energy into standard coal and carbon emissions coefficient are presented in Table 1.

Table 1. Reference coefficient and carbon emissions coefficient.

Energy Source	Reference coefficient	Emission coefficient (t/t)
Raw Coal	0.7143 (kg/kg)	0.7559
Cleaned Coal	0.9000 (kg/kg)	0.7559
Coke	0.9714 (kg/kg)	0.8550
Crude Oil	1.4286 (kg/kg)	0.5857
Gasoline	1.4714 (kg/kg)	0.5538
Diesel Oil	1.4571 (kg/kg)	0.5921
Fuel Oil	1.4286 (kg/kg)	0.6185
Natural Gas	1.3300 (kg/m ³)	0.4483
Electricity	0.1229 (kg/kW·h)	0.6800

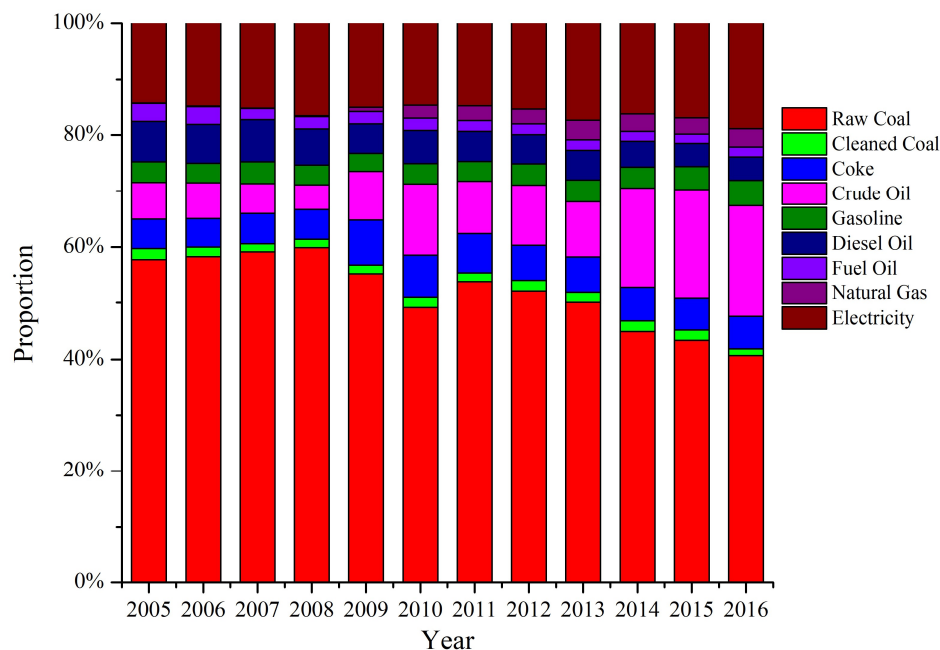


Figure 1. The CO₂ emissions from industrial energy consumption of Fujian (2005-2016).

3. Results

3.1. The CO₂ emissions of industrial energy consumption

As shown in Figure 1, the CO₂ emissions structure from various energy consumption of Fujian changes a great deal during the last 12 years. The biggest change is the CO₂ emissions from raw coal. In 2016, raw coal, crude oil and electricity are ranked in the top three CO₂ emissions. The CO₂ emissions from raw coal are the largest, from 57.73% in 2005 to 40.68% in 2016. The proportion of CO₂ emissions from raw coal has fallen the most, but it still accounts for the largest proportion of CO₂ emissions from all types of energy. This is mainly due to the reduction in the consumption of raw coal for industrial use in Fujian Province. The CO₂ emissions from crude oil have grown the fastest. In 2005, its emissions accounted for 6.58%, and in 2015-2016, it reached more than 19%. This shows that the consumption of crude oil in Fujian Province has increased rapidly. Another fast-growing is natural gas, an increase of nearly 50 times, growing from 0.07% in 2005 to 3.27% in 2016. These circumstances indicate that Fujian Province is gradually turning to relatively clean energy sources driven by China's energy conservation and emission reduction policies.

3.2. The quantity and intensity of CO₂ emissions

As shown in Table 2, the industrial output value of Fujian is only 99.96×10^{10} Chinese Yuan (CNY) in 2005. It grew steadily to 472.76×10^{10} CNY in 2016 with the rapid development of industrialization and urbanization. The annual average amount of increase was 33.89×10^{10} CNY, and the corresponding growth rate was 16.81%. Similarly, the total CO₂ emissions of industrial energy consumption increased from 44.27 million tons (Mt) in 2005 to 88.51 Mt in 2016, with an annual average increase amount of 4.02 Mt and a growth rate of 7.17%. From 2014 to 2016, the total CO₂ emissions began to decline as output values rose, indicating that industrial output was shifting towards low emissions. Moreover, in 2005-2016, the CO₂ emissions intensity gradually decreased, indicating that the energy consumption per unit of output value continued to decrease. This may be due to the adoption of new low-carbon technologies and the development of intensive industrial economy.

Table 2. The quantity and intensity of CO₂ emissions from Fujian industries (2005-2016).

Year	Industrial output value (10^{10} CNY)	Gross CO ₂ emissions (Mt)	CO ₂ emissions intensity
2005	99.96	44.27	0.44
2006	118.56	48.71	0.41
2007	144.25	54.92	0.38
2008	171.41	57.99	0.34
2009	186.81	67.46	0.36
2010	238.05	74.78	0.31
2011	303.31	85.98	0.28
2012	323.80	85.72	0.26
2013	367.25	85.25	0.23
2014	415.80	95.79	0.23
2015	438.89	92.83	0.21
2016	472.76	88.51	0.19

3.3. Analysis of driving forces of CO₂ emissions

As shown in Table 3, the total CO₂ emissions of Fujian industry increased by 44.23 Mt during 2005-2016. Among them, the industrial scale effect led to an increase of 109.11 Mt of CO₂ emissions. The energy structure effect contributed a reduction of 41.8 Mt of CO₂ emissions. The energy intensity effect caused a reduction in CO₂ emissions by 60.7 Mt.

The industrial scale effect was the main driving factor for the growth of CO₂ emissions in Fujian industry sector. In terms of the cumulative effect, the positive impact of the industrial scale effect on carbon emissions in 2016 was 246.67% of the total effect. Since 2005, with the rapid development of economy, the carbon emissions from Fujian industry sector had been increasing gradually. The increase

caused by the industrial scale had been maintained at around 40% of the total CO₂ emissions increase (see Figure 2). It declined in 2015-2016 and dropped to around 30%.

The energy intensity effect was the main inhibitor of the growth of CO₂ emissions. From the cumulative effect, the negative impact of the energy intensity effect on carbon emissions in 2016 was -137.22% of the total effect. The energy intensity of CO₂ emissions in Fujian industrial economy continued to decline during 2005-2016. In 2016, the energy intensity in Fujian decreased by 56.82% compared with 2005, with an average annual decline of 5.17%. The decline in energy intensity had effectively alleviated the emissions increase due to industrial scale effects, which caused the growth rate of total CO₂ emissions in Fujian to be lower than industrial output growth.

The energy structure effect had only a weak positive or negative impact on Fujian industrial CO₂ emissions. Due to lack of resources, most of Fujian's demand for energy came from other places. For a long time, the energy structure was single. The consumption proportion of low-carbon energy was still small although it gradually increased.

Table 3. Decomposition of industrial CO₂ emissions in Fujian (2005-2016).

Year	Energy structure effect	Energy intensity effect	Industrial scale effect	Total effect
2006	0.05	-3.54	7.93	4.44
2007	0.13	-4.06	10.14	6.21
2008	0.22	-6.89	9.73	3.07
2009	-0.37	4.48	5.36	9.47
2010	-1.67	-8.18	17.16	7.32
2011	0.7	-8.92	19.41	11.2
2012	-0.47	-5.4	5.61	-0.26
2013	-0.47	-10.76	10.76	-0.47
2014	-1.38	0.75	11.18	10.55
2015	-0.34	-7.72	5.1	-2.96
2016	-0.59	-10.47	6.73	-4.32
Sum	-4.18	-60.7	109.11	44.23

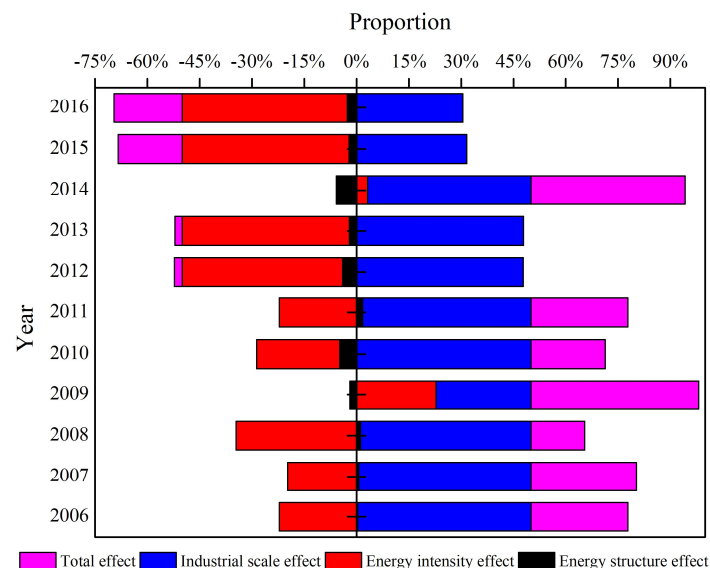


Figure 2. Decomposition of CO₂ emission increment in Fujian (2005-2016).

3.4. Policy implications

It is necessary to promulgate the policies and regulations for CO₂ mitigation. To eliminate the CO₂ emissions effectively, it suggests some measures as follows.

(1) The government should eliminate backward production capacity, improve access standards, and limit the development of high-carbon industries. Furthermore, it is imperative to vigorously develop industries with high value-added and low carbon emissions, such as advanced manufacturing. At the same time, the government and enterprises should increase investment in science and technology to promote the progress of low-carbon technology.

(2) The government should encourage to reduce the use of energy with a large carbon emission further, such as coal and oil, and to develop and utilize clean energy such as electricity, natural gas, solar energy and wind energy.

(3) It is necessary to establish cooperation and exchange mechanism with developed countries to jointly develop advanced emission reduction technologies, carbon dioxide capture and storage technology. At the same time, take full advantage of the Clean Development Mechanism (CDM) project to reduce carbon dioxide emissions with advanced technology, capital and experience from abroad.

4. Conclusion

A decomposition analysis based on the LMDI method covering the years from 2005 to 2016 is performed to investigate the main driving forces behind energy-related CO₂ emissions variations in Fujian Province, China. Based on the empirical results, we find that raw coal, crude oil and electricity are ranked in the top three CO₂ emissions. The proportion of CO₂ emissions from raw coal still accounts for the largest proportion of CO₂ emissions from all types of energy. The industrial scale effect was the main driving factor for the growth of CO₂ emissions in Fujian industry sector. The energy intensity effect was the main inhibitor of the growth of CO₂ emissions. The energy structure effect had only a weak positive or negative impact on Fujian industrial CO₂ emissions.

Some potential policy implications are put forward on mitigating energy-related carbon emissions in Fujian. The government should optimize the industrial structure within the industry and promote the progress of low-carbon technology. It also should encourage to reduce the use of energy with a large carbon emission and develop and utilize clean energy. It is necessary to establish cooperation and exchange mechanism with developed countries to jointly develop advanced emission reduction technologies.

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