

What Causes the Difference in PM_{2.5} Emissions among Regions: The Perspective of Social Economic Factors

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Abstract

With the rapid development of China's economy, the differences in economic levels among regions have been increasing. It directly affects the demand for terminal fossil energy among regions. The discharge of a large amount of particulate matter in the process of energy consumption which brings great pressure to the control of regional pollution. Therefore, it is of great theoretical and practical significance to study the affecting factors of the difference of PM_{2.5} emissions caused by fossil energy consumption in various regions of China. By 2010-2016 National Energy Balance Sheet data terminal sector energy consumption estimated the PM_{2.5} emissions of energy consumption and confirmed PM_{2.5} emissions mainly from coal consumption, thus further analyzed each region PM_{2.5} emission efficiency and status. On this basis, through the constructed LMDI model, the factors which influence PM_{2.5} emissions measured in this paper are decomposed into eight factors: industrial emission intensity, industrial structure, economic scale, population size, etc. The results show that: 1) Economic growth is the decisive factor. The difference between PM_{2.5} emissions among regions has a high single trend with economic development. Each region should improve the quality of economic development and achieve Pareto optimality for economic development and environmental governance. 2) Compared with the eastern region, the central and western regions have lower technical level, which means higher marginal PM_{2.5} emission reduction potential. Based on the above conclusions, it is necessary to focus on the sub-regions to reduce emissions and control the pollutant while fully reflecting the characteristics of regional emission reduction.

Keywords

PM_{2.5}, Region Difference, LMDI, Energy Consumption

1. Introduction

With the rapid development of China's economy in recent years, the differences in the level of economic development in various regions of China are gradually increasing. The process of economic development has caused a great negative impact on the quality of the air environment. The most typical is the proliferation of haze pollution. It has become one of the most important reasons for the decline in air quality in China. However, China's haze pollution does not happen in a single regional, but in a large area in various regions, and the trend of haze pollution is increasingly regionalized, with total coverage of more than 1.3 million square kilometers.

PM_{2.5} is one of the most important indicators to measure the severity of haze, which refers to inhalable particles with a diameter or particle size of fewer than 2.5 microns. In haze weather, human inevitably inhale PM_{2.5} particles in daily activities, which has a huge impact on human health, such as: endanger human body's respiratory system, heart system, etc.. According to the national temperament number published by the Environmental Protection Agency, The haze level of Jinan City ranks the first in the country (Shandong Environmental Protection Bureau,2015), which has become the city with the highest mortality rate due to fine particles. As for fine particulate matter pollution, there is much scientific evidence to prove that fossil energy consumption, especially coal consumption, is the main contribution to the formation of fine particulate matter. The economic development patterns of various regions in China are not consistent, and the emission intensity of PM_{2.5} generated by interregional fossil energy consumption is not the same. By analyzing the driving factors and emission intensity differences behind PM_{2.5} emissions in various regions of China, it is helpful to evaluate the interregional PM_{2.5} emissions levels and provide effective strategies for the government to develop differently PM_{2.5} emission reduction policies for different regions.

In order to further explore the problem, this article takes the eastern and western regions as the object, measures PM_{2.5} emissions generated by energy consumption in 30 provinces, build a comprehensive and improved LMDI decomposition model and quantitatively analyzes PM_{2.5} emissions between the eastern, central and western regions. The influencing factors are also decomposed. At the same time, in the future, energy consumption will contribute to building a better environmentally friendly China on the basis of the "13th Five-Year Plan" [1].

2. Literature Review

The earliest research on PM_{2.5} dates back to the first US monitoring of PM_{2.5} in the 1980s. The time when domestic researchers began to research on PM_{2.5} is relatively short, with the improvement of national economic development and the importance of environmental protection, the study of PM_{2.5} pollutants have attracted the attention of the academic community. The current research on

PM_{2.5} focuses on the following categories:

The first type of research, from the perspective of natural science, studies the formation of PM_{2.5} particles, focusing on source interpretation, meteorological characteristics, human health, as well as chemical mechanisms. Federico Karagulian, Song Na, *et al.* explained the physical and chemical processes of PM_{2.5} particles, and made relevant research on the impact of human health. The study found that PM_{2.5} emissions mainly come from industrial activities, biomass burning, and gas emissions from the motor vehicle, building dust, etc. [2] [3] [4] [5]. Jia Mengwei *et al.* studied the seasonal variation characteristics of atmospheric pollutants such as PM_{2.5} and the distribution of meteorological influence factors found that the seasonal distribution of PM_{2.5} concentration was low in winter and summer, and higher in midnight and noon, the concentration is inversely proportional to the temperature, and the pollution level of PM_{2.5} is lower in areas with larger rainfall [6] [7] [8] [9].

The second type of research gradually realizes the importance of studying the social and economic drivers of PM_{2.5} emissions, and beg/in to study it from the perspective of economics. Previous studies on social and economic drivers can be divided into three levels: national, regional and urban level.

1) At the national level. Ji *et al.* select panel data of 79 developing countries from 2001 to 2010, using the STRIPAT model decomposition method to examine the effects of the income of per capita, the industrial structure, the level of urbanization, the energy intensity and the population expansion to PM_{2.5} concentration. The results show that there is an inverted U-shaped relationship between per capita income, urbanization level and PM_{2.5} concentration [10]; 2) Regional perspective. Zhou Shudong constructed a two-stage distribution lag model of PM_{2.5} concentration analyzed the environmental and economic factors of emissions in the Beijing-Tianjin wing area, and the results showed that the region's coal consumption, the added value of heavy pollution industry and the amount of yellow-labeled vehicles have a great positive impact on the emission of atmospheric pollutants in the region [10]. Mao Wanliu uses spatial measurement model to analyze the spatial and temporal pattern and influencing factors of PM_{2.5} pollution in the Yangtze River Delta region and the results show that there is a concentration phenomenon in the region, and the smoke and secondary transformation of combustion emissions have a great impact on the PM_{2.5} in the Yangtze River Delta region [11]; 3) Provincial level. In 2016, Shao Shuai conducted a substantive discussion on whether there is an EKC curve between the PM_{2.5} pollution and GDP per capita in each province, and focused on the provinces that crossed the inflection point [12]. Ma Yanran used SAR model and OLS estimation to verify the existence of the short-term EKC curve for the distribution of haze pollution in 2014, and the results showed that the EKC curve was at a turning point when the per capita GDP of the province was between 41,787 yuan and 48,066 yuan [13]. There are some following shortcomings by a review of the above literature:

First, the estimate of PM_{2.5} primary source emissions are more focused on a certain industry or sub-city area, and there is no research on the contribution effects of multiple industries. For example, Chen Hanbin and Li Pupu considered that under the circumstances of the efficiency and distribution rate of pollution control technologies, the PM_{2.5} primary source emissions limited to the industry in Tangshan City are estimated and decomposed. However, this type estimation method is difficult to be put into practical use, so it is generally used for narrow regional industry estimation, which is not conducive to study the factors for interregional PM_{2.5} emission and few studies have decomposed PM_{2.5} particulate matter emitted by fossil energy consumption [14].

Second, the current literature focuses on the study of carbon emission estimation and decomposition. The literature on estimating or decomposing PM_{2.5} emissions from fossil energy consumption in the economic sector is rare.

The contribution of this paper is to select the PM_{2.5} emissions of fossil energy consumption as the research index. Compared with the primary source estimation in the above literature, the PM_{2.5} emission factors generated by fossil energy consumption in the terminal sector will not be greatly fluctuated due to the improvement of technical efficiency, and there is a considerable degree of rationality, a convenient method, which can meet the estimation of PM_{2.5} emissions from interregional terminal sectors. At the same time, the factor decomposition method is used to analyze the driving factors; the method is simple and convenient. The decomposition has no residual value, which is suitable for the research and analysis of the paper.

3. Data Processing

3.1. Accounting Formulas and Data Resources

At present, there are few studies on the PM_{2.5} emissions of fossil energy consumption at home and abroad, especially the differences in the factors affecting the PM_{2.5} emissions of fossil energy consumption among regions. Based on the comprehensive balance sheet of local energy statistics, the paper estimates the PM_{2.5} emissions from all kinds of energy consumption in terminal sectors except heat, liquefied natural gas, and other energy sources. What needs to be specially explained is that electric energy is the main factor that makes the conversion of coal consumption happen, and the power consumption of the terminal department does not include the course of processing. In fact, the consumption of electric energy in the terminal sector is mainly the consumption of coal, so the paper takes electricity into account while introducing energy.

This article is based on the energy consumption data of the terminal sector from the local energy consumption balance sheets, which involves data of 30 provinces from 2010 to 2016. The PM_{2.5} emissions generated by the terminal departments of each province are calculated by the formula (1).

$$PM = \sum_{i=1}^3 P_i * l_i, \quad i = 1, 2, 3 \quad (1)$$

Among them, PM represents the emission of energy consumption, P_i represents the emission factor of the i -th energy, and l_i represents the consumption of i -th energy, which is expressed as coal, oil, natural gas, and electricity. In view of the data selected in this paper is relatively short, the emission factors generated by each energy consumption will not change much due to the technological advancement or energy utilization. While considering the emission factor as static, based on the research of Zhao Bin and Zheng Ming, the pollutant emissions from the energy consumption of each terminal department are obtained [14] [15] as shown in **Table 1**.

In order to accurately calculate the $PM_{2.5}$ emissions from energy consumption, **Table 1** divides all energy into four categories: coal-based fuels, petroleum-based fuels, natural gas-based fuels, and electrical fuels. The $PM_{2.5}$ emissions per unit of energy consumption are measured by the consumption emission factor in g/kg.

3.2. Model Construction

The paper constructs a comprehensive and improved LMDI model to decompose and analyze the growth of $PM_{2.5}$ emissions in China, and decomposes the total emissions from China's terminal energy consumption into 30 provinces, the sum of the driving contribution effects of three economic sectors (industrial,

Table 1. $PM_{2.5}$ Energy consumption emission factor.

Category	Fuel Name	Average Low Fever (Kj/kg·m ³)	$PM_{2.5}$ Energy Emission Factors
Coal Fuels	Coal	20910	0.74
	Washing Coal	26350	0.74
	Other coal Washing	8350	0.74
	Coal	20910	0.74
	Coke	28450	0.144
	Blast Gas	3763	0.17
	Coke Oven Gas	16700	0.17
	Converter Gas	1900	0.17
	Other Gas	7945	0.17
Oil Fuels	Crude Oil	41820	0.31
	Gasoline	43082	0.125
	Kerosene	43082	0.31
	Diesel	42700	0.31
	Fuel Oil	41820	0.31
	Liquefied Petroleum Gas	50200	0.15
Natural Gas	Natural Gas	39000	0.17
Power	Terminal Power	3763	0.09

transportation, and others). Then the effects of the three regions are summed up by provinces. The decomposition model is as follows:

$$PM = \sum_{i=1}^{30} \sum_{j=1}^3 \frac{PM_{ij}}{Y_{ij}} \frac{Y_{ij}}{Y_i} \frac{Y_i}{P_i} P_i = \sum_{i=1}^{30} \sum_{j=1}^3 I_{ij} K_{ij} S_i P_i \quad (2)$$

In formula (2), the amount of emissions from the j -th sector of the i -th province due to energy consumption is expressed as PM_{ij} (unit: ton), Y_{ij} indicates the nominal value added by the j -th department of the i -th province (unit: 100 million yuan), Y_i indicates the nominal GDP of the i -th province (unit: 100 million yuan), P_i indicates the population size of the i -th province (unit: 10,000 people), I_{ij} indicates the emission intensity of the j -th economic sector in the i -th province, K_{ij} indicates the structure proportion of the j -th department of the i -th province, S_i represents the per capita living standard of the i -th province.

According to the LMDI I decomposition method, the decomposition of each province's $PM_{2.5}$ emissions can be expressed as:

$$\Delta PM = \Delta PM_I + \Delta PM_J + \Delta PM_S + PM_P \quad (3)$$

$$\Delta PM_I = \sum_{i=1}^{30} \sum_{j=1}^3 W_{ij} LN \frac{I_{ij}^T}{I_{ij}^0} \quad (4)$$

$$\Delta PM_J = \sum_{i=1}^{30} \sum_{j=1}^3 W_{ij} LN \frac{I_{ij}^T}{I_{ij}^0} \quad (5)$$

$$\Delta PM_S = \sum_{i=1}^{30} \sum_{j=1}^3 W_{ij} LN \frac{S_i^T}{S_i^0} \quad (6)$$

$$\Delta PM_P = \sum_{i=1}^{30} \sum_{j=1}^3 W_{ij} LN \frac{J_i^T}{J_i^0} \quad (7)$$

$$W_{ij} = \frac{PM_{ij}^T - PM_{ij}^0}{LN PM_{ij}^T - LN PM_{ij}^0} \quad (8)$$

In formula (3), PM_I , PM_J , PM_S and PM_P respectively represent changes in emissions that result from economic sector emission intensity effects, industrial structure effects, economic scale effects, and population size effects.

4. Empirical Analysis

4.1. Analysis of the Current Situation of China's Three Major Regional $PM_{2.5}$ Emissions from 2010 to 2016

Energy consumption refers to the number of various energy sources produced and consumed by the terminal department for a certain period of time after deducting the consumption and loss of the secondary energy used for processing. The data of emissions in this paper are collected from the energy consumption of the terminal department. In order to ensure the accuracy of the emissions statistics, the paper selects the provincial energy balance table and the database of CNKI to estimate the emissions, whose results are relatively close to reality. **Fig-**

Figure 1 shows the trend of the three major regional emissions from 2010 to 2016. The change in regional emission trends reflects the consistency between regional economic development and energy demand. The eastern region is economically developed, with strong research and development capabilities for energy-saving technologies and environmental protection techniques, high transportation costs, and the decreasing demand for energy consumption. The central and western regions are rich in coal and natural gas resources, and the energy consumption costs are low. In recent years, energy consumption has been continuously reduced during the development of the economy. Therefore, although the eastern region is a region with high energy consumption, with the development of new energy alternatives and pollution control, the emissions in the eastern region have been shrinking, while the central and western regions have continued to increase their energy demand with the development of regional economies, and the emissions have an upward trend. In 2012, China issued the “Twelfth Five-Year Plan for Air Pollution Prevention and Control in Key Areas”, which put the emission level as a key control target. In 2013, the first implementation year of the policy, under the influence of the policy, there was a large decline in emissions in various regions of China. From 2013 to 2016, China’s economy continued to recover from the “financial crisis”. At the same time, the government implemented a series of industrial policies to stimulate industries, as well as constantly upgrading the industries in the eastern region. The high-energy-consuming industries continued to be converted to the central and western regions, and the economic development gap between regions had narrowed to some extent. The interregional energy consumption level and emission level among regions are close to equilibrium.

1) Analysis of Current PM_{2.5} Emission Status

In general, Hebei, Shandong, Inner Mongolia, Hunan, Shanxi, Hubei, Jiangxi, Guangdong, Henan, and Heilongjiang are the major provinces that contribute to China’s emissions, whose total contribution is up to 53% of the emissions. The national emissions are mainly concentrated in the eastern region extending to

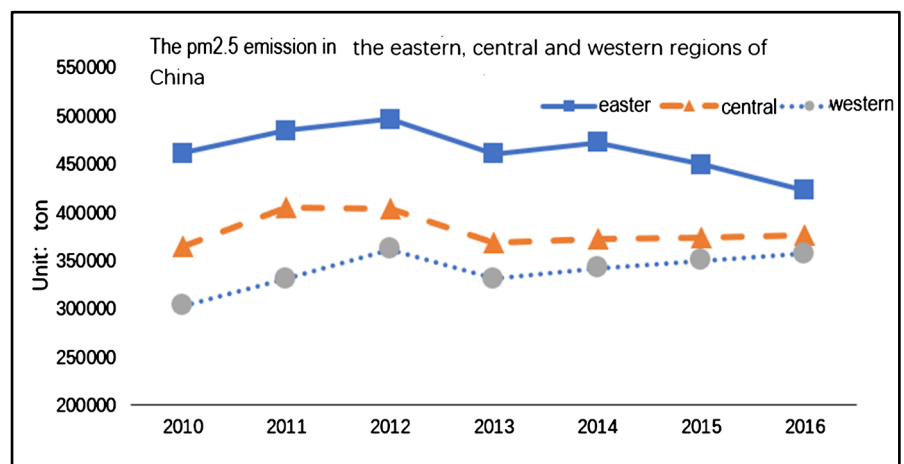


Figure 1. Total emissions of various regions from 2010 to 2016.

the midwest, which is constantly declining (Figure 2). The eastern region is in a superior coastal position whose economic development is fast and attracts far more foreign investment than the central and western regions. The average energy consumption is 32,000 tons due to the relatively high energy consumption. However, with the standards of the pollution treatment in the eastern provinces are rising, and accelerate industrial upgrading, expensive raw materials and labor costs are forcing many large polluters in first-tier cities to search for new production areas. The central region is a major agricultural town with a poor economic base, high population density, low energy consumption costs, and the local government provides better preferential policies for the introduction of enterprises, which greatly stimulate the transfer of high-polluting enterprises in the east. At the same time, the central region is easy to ignore environmental protection when it undertakes the transfer of the east, and consumes a large amount of energy to promote economic development, but emits more, which aggravates the contradiction between economic development and ecological environmental protection. The average emissions in the central region are 38,000 tons. Compared with the eastern and central regions, the western region is underdeveloped, with a small population density and a lack of high-pollution industrial production environment, thus has a low level of emissions.

2) Analysis of the Difference in Economic Emission Intensity

PM_{2.5} Emission intensity refers to the amount of pollution discharged by per unit of GDP, which represents the environmental load of the economic value per unit and reflects the level of economic development capacity and pollution control capacity among regions. The lower the emission intensity, the stronger the environmental protection technology capability is. The distribution of emission intensity in China is basically similar to the difference in the economic development level among regions. The average emission intensity in the eastern, central and western regions is 1.1, 2.3, and 3.0 ten thousand tons/trillion yuan. The

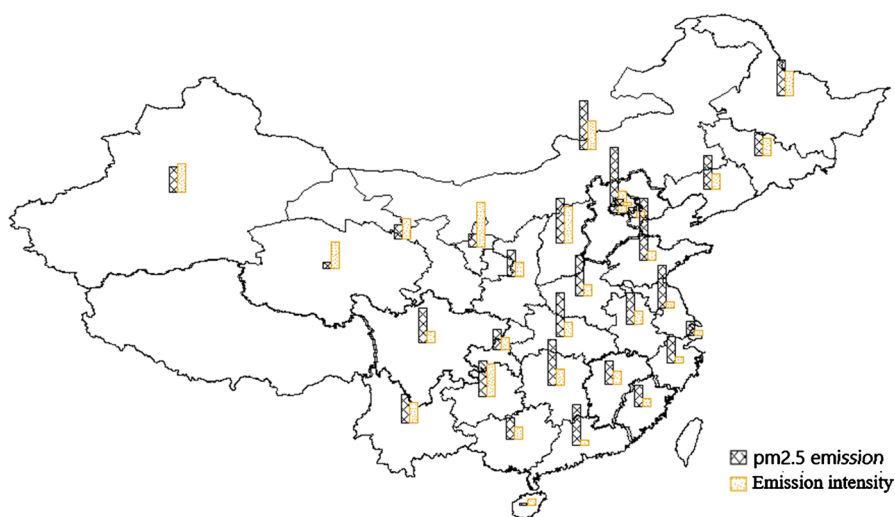


Figure 2. Distribution of emissions and emission intensity by the province in 2016 (unit: 10,000 tons).

eastern region is economically developed, local investors and managers are more willing to invest in optimizing clean technology, while the central and western regions have more extensive economic production methods, and the economy is more dependent on energy consumption in the process of development, which results in lower emission intensity in the eastern region and higher emission intensity in the midwest. Take Beijing as an example, it has the lowest economic emission intensity, while Ningxia has the highest economic emission intensity. Although the northeast of China is located in the eastern part, economic development is mainly driven by heavy industry and high energy-consuming industries, which makes the emission intensity is relatively high.

3) Analysis of Factors Affecting PM_{2.5} Emission Reductions in Various Provinces from 2010 to 2016 (Figure 3)

Eastern Region: From 2010 to 2016, PM_{2.5} emissions in the Shandong province have decreased by 29,400 tons, which is the main emission reduction province in the eastern region. It also shows that the “Twelfth Five-Year Plan” of Shandong Province has been implemented and has effectively suppressed the growth of emissions. Chinese steel data statistics in 2015 show that the steel output in Hebei ranks first in the country for 17 consecutive years, whose capacity of producing steel exceeds 200 million tons, which accounts for more than one-fifth of the total in China. It is a major province of heavy industry in China. The coal and iron resources are abundant. Under the stimulation of abundant energy, the emissions do not fall but rise, and will remain at a high level. The provinces with the lower overall emissions and small changes in the eastern region are Hainan, Tianjin, Fujian, and Zhejiang.

In the central and western regions, the per capita GDP increased by 66% and 74% respectively from 2010 to 2016. The regional economic development stimulates the demand for energy. Except for the effective suppression of emissions in Hubei, Henan, Sichuan, and Chongqing, the energy consumption in other provinces continues to increase.

4.2. Analysis of Factors Affecting Interregional PM_{2.5} Emissions

Table 2 and Figure 4 show that economic growth is the main positive factor of

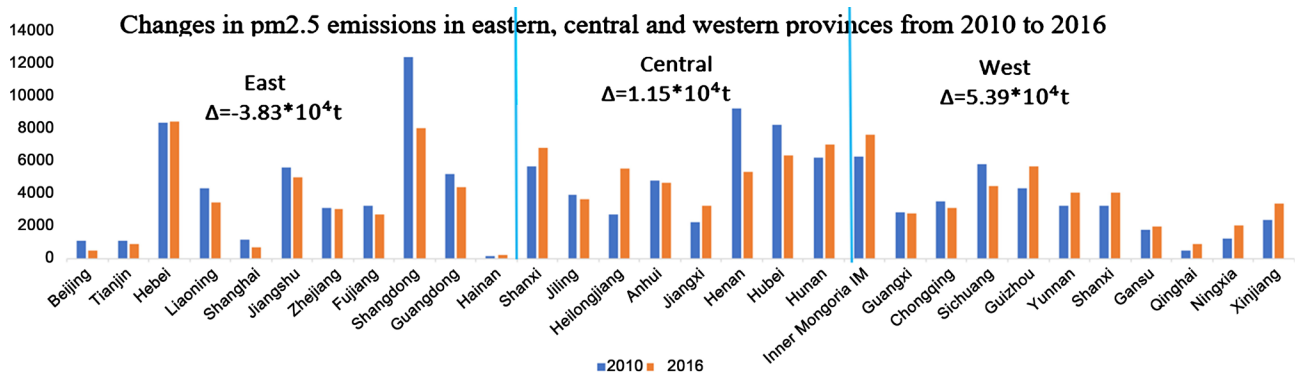
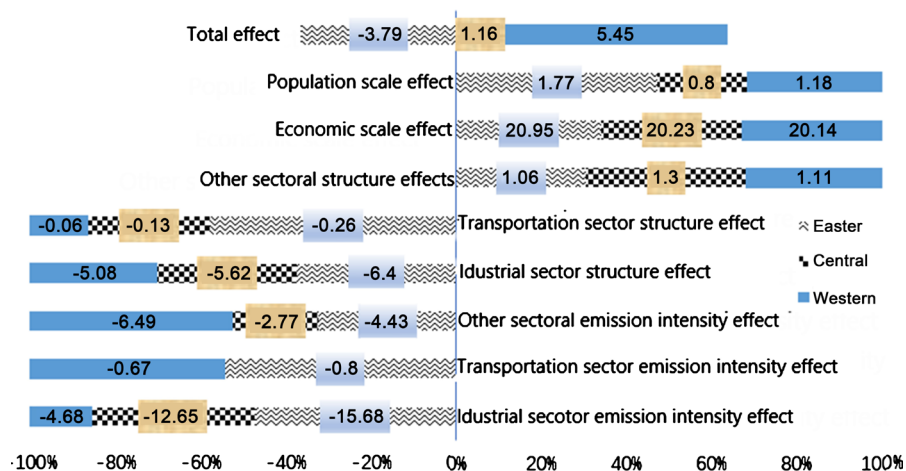


Figure 3. Change in emissions of the eastern, central and western provinces from 2010 to 2016.

Table 2. Decomposition analysis of China's PM_{2.5} emission drivers by region from 2010 to 2016.

Regional	Industrial Emission Intensity Effect	Traffic Emission Intensity Effect	Emission Intensity Effects in Other Sectors	Industrial Structural Effects	Traffic Structure Effect	Structural Effects in Other Sectors	Economic Scale Effect	Population Size Effect	Total Effect
Eastern	-15.6	-0.8	-4.43	-6.4	-0.26	1.06	20.95	1.77	-3.79
Central	-12.6	0	-2.77	-5.62	-0.13	1.3	20.23	0.8	1.16
Western	-4.68	-0.67	-6.49	-5.08	-0.06	1.11	20.14	1.18	5.45
National	-33.0	-1.47	-13.69	-17.1	-0.45	3.47	61.32	3.75	2.82

**Figure 4.** Decomposition analysis of PM_{2.5} emission factors in the eastern, central and western regions from 2010 to 2016

emissions, and the economic effect contributes 20.95, 20.23, and 20.14 ten thousand tons of positive emissions in the east, middle and west, respectively. The difference in the economic scale of the three regions is small; the per capita GDP growth is 55% and 66% respectively. The central and western regions consume a lot of energy for developing the economy, and the eastern region, as the most developed economy, has been the most important region for energy consumption. The industrial emission intensity is the main driving factor for emission reduction, whose contribution to the eastern, central and western regions is -15.6, -12.6, -4.68 ten thousand tons, respectively, indicating that the industrial emissions in the eastern region are better treated, which further reflect that there is significant potential for improving energy efficiency in the central and western regions to promote emission reduction. The industrial structure of each region has a negative effect, which indicates that there is significant progress in the governance of regional structure, whose essence is that the economic development mode has been effectively transformed. The most significant contribution to the industrial structure is the industrial structure effect, and its contributions among regions are: -6.4, -5.62, -5.08 ten thousand tons. The effects in the eastern, central and western regions are: -3.79, 1.16, and 5.45 ten thousand tons respectively. At the regional emission reduction level, the eastern region is the main region for reducing emissions, while the central and western regions are the main re-

gions for increasing emissions (Table 3).

During the period of research, China has been implementing policy control over regional emissions. The Chinese Environmental Protection Agency put forward a series of guidance opinions on controlling regional air quality in 2010, which emphasizes that particulate matter is a key pollutant, and it is required to pay attention to the pollution of certain industries. In the first year of the policy, emissions increased rapidly. In December 2011, China re-emphasized the control of particulate matter emissions in the “Environmental Protection Twelfth Five-Year Plan”, and required energy-consuming enterprises to continuously improve the pollution emission control capacity. In 2012, China’s “Twelfth Five-Year Plan for Air Pollution Prevention and Control in Key Areas” re-emphasized the implementation of emission control and strengthening the discharge of key industries. At the same time, during the period of 2011 to 2013, China’s regional economy gradually recovered from the financial crisis, benefiting from economic development and policy support, and the efficiency of pollution control continued to increase, which makes the energy emission intensity effect especially obvious for emission reduction. After 2013, according to the environmental requirements of the “Twelfth Five-Year Plan”, the emission concentration of each region has doubled within five years, but there are large differences in economic development levels in various regions, and the emissions of particulate matter varies a lot, which shows that the eastern region has a high level of economic development, and the comprehensive capacity of environmental management is

Table 3. Time decomposition analysis of the driving factors of Eastern, Central, and Western PM_{2.5} emission from 2010 to 2016.

Area	Variable	Year						Total effect
		2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	
Eastern	Emission Intensity Effect	-0.53	-3.05	-6.71	-1.8	-3.53	-4.82	-20.46
	Industrial Structure Effect	-0.27	-0.84	-1.4	-0.62	-1.63	-1.88	-11.51
	Economic Growth Effect	2.86	4.7	4.18	3.34	2.6	2.97	20.66
	Population Size Effect	0.35	0.36	0.31	0.29	0.28	0.33	1.9
	Total Effect	2.4	1.17	-3.62	1.22	-2.28	-2.71	-3.83
Central	Emission Intensity Effect	-0.33	-4.62	-5.92	-2	-0.46	-2	-15.34
	Industrial Structure Effect	0.47	-0.43	-1.07	-0.6	-1.48	-0.79	-3.89
	Economic Growth Effect	3.81	4.71	3.46	2.74	1.9	2.91	19.53
	Population Size Effect	0.09	0.13	0.14	0.15	0.18	0.16	0.86
	Total Effect	4.03	-0.22	-3.38	0.31	0.14	0.29	1.17
West	Emission Intensity Effect	-1.22	-1.38	-5.87	-1.36	0.64	-0.98	-10.17
	Industrial Structure Effect	0.26	-0.43	-0.97	-0.53	-1.67	-1.13	-4.45
	Economic Growth Effect	3.58	4.73	3.58	2.8	1.53	2.56	18.78
	Population Size Effect	0.13	0.19	0.2	0.18	0.27	0.26	1.23
	Total Effect	2.76	3.11	-3.06	1.09	0.78	0.7	5.39

strong, the emission intensity effect and total effect are more obvious for emission reduction. The central and western regions are rich in resources, whose economic development mainly depends on high energy-consuming and labor-intensive industries, thus has a lower reduction for emissions. According to national statistics, the proportion of agricultural added value is less than 15% from 2010 to 2014, and the proportion of agricultural labor is less than 30%, showing that China is in the stage of industrial economy, and the effect of industrial structure on this period is not obvious to the emission reduction. After 2014, China was in the transition period from the industrial economy to a service economy. By 2015, the value-added ratio of China's service industry exceeded 50%, and the proportion of service labor force exceeded 40%. During this period of time, the industrial structure has been continuously upgraded and modernized, and the proportion of industrial labor has been continuously reduced. In this year, the industrial structure effect is particularly obvious for emission reduction. It is pointed out that when social-economic development reaches a certain level, the population growth rate will decrease accordingly. In addition, China has implemented the family planning policy for nearly 30 years. Under the dual effect, the fertility rate has continued to decline, which shows that the population effect of China has not changed much during the "Twelfth Five-Year Plan" period.

5. Conclusions and Suggestions

Using the research data of 30 provinces in China from 2010 to 2016, the paper explores the different factors in emissions in China's three regions, and come to the following conclusions: 1) Four driving factors for emission differences are economic scale, emission intensity, structure effects, and population effects. Among them, economic growth is the decisive factor. 2) Compared with the eastern region, the central and western regions have lower technical levels, higher marginal emission reduction potential, and higher energy efficiency can reduce emissions more effectively in the central and western regions. 3) For every one ton increase in coal consumption, the emission will increase by 0.74 kg. The consumption of coal among regions directly determines the difference in inter-regional emission levels.

Particulate matter pollution is not only an environmental problem but also as the matter of fact is the immaturity of social and economic development, which provides the most basic material conditions for the discharge of particulate matter. At present, the Chinese social economy is in the process of development, and it is necessary to do well in regional control and emission reduction across the country. What's more, it is of great significance to control haze pollution under the conditions of regional synergies in various provinces and to make different policies with different degrees of economic development on the premise of adhering to local conditions. In general, there are different management policies that meet the diverse attributes of each region and can achieve effective emission

reduction. Here are some suggestions that can promote emission reduction:

1) Transform the mode of economic growth. Chinese current economic growth mode mainly relies on increasing labor and large-scale capital investment. In the process of economic growth, it consumes a large amount of energy. All regions should continuously promote the transformation of economic growth mode, so that to achieve resource-efficient production, and develop a decoupling and coordinate relationship between economic development and particulate matter emissions.

2) Optimize the industrial structure. Local governments should use economic and administrative means to support industrial upgrading, encourage technological innovation in industries relying on large amount of energy consumption, continuously eliminate backward mechanisms, update technological equipment, and vigorously develop advanced technology, reduce interregional emission intensity, while paying attention to green industries and encouraging development, and promoting the continuous modernization of regional industrial structure.

3) Optimize the energy consumption structure, reduce the consumption of coal resources, and promote the use of clean energy. Especially in provinces with abundant coal resources, they need to optimize coal combustion technologies, improve coal combustion efficiency, and reduce energy consumption intensity. At the same time, we should vigorously promote the use of new energy technologies to provide policy support and subsidies for the development of new energy, thus to curb the consumption of coal, which can promote the shift of coal-based energy consumption structure to the new energy in all economic sectors in China.

4) From 2010 to 2016, the average actual fixed investment amount in the eastern, central and western regions was 1.32, 1.11 and 0.68 trillion yuan respectively. Fixed assets will consume a lot of energy in the investment process and have a significant impact on pollutant emissions. A considerable proportion of Chinese export is the export of high-energy-consuming products (guan *et al.*, 2014), which is mainly high-energy-consuming products. Therefore, we can reduce the proportion of exports of high-energy-consuming products through taxation, subsidize and support the export of technology products and reduce emissions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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