Analysis of the Factors Influencing Energy Consumption in the Pearl River Delta Region based on the LMDI Method

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Abstract. This paper uses the LMDI decomposition method to investigate the extent to which economic development, industrial level, population size, urbanization, energy intensity, and energy structure affect total energy consumption in the PRD region during the period 2014-2021. The findings show that economic development and population growth are the main factors driving the rise in energy consumption, while industrial level and energy intensity can curb the growth of energy consumption to the maximum extent. Finally, in response to the findings, recommendations are made that the PRD region should continue to improve energy governance, promote green structural transformation of energy, and cultivate residents' energy-saving and environmentally friendly consumption concepts.

Keywords: Pearl River Delta region; Energy consumption; LMDI decomposition method; Low carbon development.

1 Introduction

China has put forward the vision of peaking carbon dioxide emissions and carbon neutrality in 2020, showing the great power's responsibility to a community with a shared future for mankind. In the future, China will focus on developing a green, efficient, and sustainable consumption and production model. The Pearl River Delta (PRD) region is deployed as the core construction area of the Guangdong-Hong Kong-Macao Greater Bay Area on “Belt and Road” economic development strategy in China. In 2016, nine municipal governments in the PRD region signed the *Shenzhen Declaration on Green and Low-carbon Development of the PRD City Cluster*, expressing their determination to strive for the first peak of CO_2 emissions in the PRD region[1]. This shows the enormity of the current task of energy conservation, emission reduction, and environmental protection in the region. Therefore, it’s necessary to investigate the characteristics of energy consumption in the PRD region and its influencing factors, to find countermeasures and suggestions that are conducive to the future transformation of the energy structure and sustainable development of the PRD region. The following factors are generally considered in traditional studies about the influencing factors of energy consumption: level of socio-economic development, income level of the population, demographic structure, energy prices, energy structure, lifestyle, and technology level[2]. Related research has involved several important results and innovative approaches, but there are some shortcomings as follows: the scope of research is mostly based on the overall

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situation of the whole country, and there is less in-depth research on a specific region; there are fewer resources in the literature on energy consumption in the PRD region; some of the studies are not comprehensive in the selection of energy consumption influencing factors when using the LMDI method. Therefore, this paper hopes to apply the LMDI method to construct a constant equation for the decomposition of total energy consumption in the PRD region, take into account all the important influencing factors as far as possible, add the factor of industrial development level, make a detailed analysis and on the effect, degree, and direction of each influencing factor, to providing academic basis and suggestions for the control of energy consumption.

2 Research Objective

To target energy use issues within the PRD region, this study decomposes the factors of energy consumption in the PRD region through the LMDI method and proposes effective measures to improve energy consumption and energy utilization in the PRD region based on the analysis results, to promote the construction of a low-carbon economy and society in the PRD region and achieve the commitment of the core economic region to take the lead in carbon emissions.

3 Methods

This paper sets the time frame at 2014-2021 and explores the contribution of six factors (population size, urbanization level, economic development level, industrial production level, energy intensity, and energy structure) to total energy consumption in the nine cities of the PRD region (Guangzhou, Foshan, Dongguan, Shenzhen, Zhuhai, Zhaoqing, Jiangmen, Huizhou, and Zhongshan).

3.1 LMDI Model Setting

Set the total energy consumption of the nine cities in the Pearl River Delta as $\sum_{ij} E_{ij}$, constructing the following equation:

$$\sum_{ij} E_{ij} = \sum_{ij} P \times \frac{P_i}{P} \times \frac{G_i}{P_i} \times \frac{Q_i}{G_i} \times \frac{E_i}{Q_i} \times \frac{E_{ij}}{E_i} \tag{1}$$

where i denotes different cities, j denotes the type of energy, P denotes the population size, P_i denotes the urban residential population in each city, Q_i denotes the GDP of each city in the PRD, G_i denotes the urban GDP of each city in the PRD, E_i denotes the total energy consumption of each city in the PRD, and E_{ij} denotes the consumption of a certain type of energy source in each city.

Thus, the total energy consumption of the PRD region can be decomposed as follows:

$$\sum_{ij} E_{ij} = \sum_{ij} P \times \frac{P_i}{P} \times \frac{G_i}{P_i} \times \frac{Q_i}{G_i} \times \frac{E_i}{Q_i} \times \frac{E_{ij}}{E_i} = \sum_{ij} P \times \rho \times g \times q \times c \times e \tag{2}$$

$$E_t - E_0 = \Delta E = \Delta P + \Delta \rho + \Delta g + \Delta q + \Delta c + \Delta e \tag{3}$$

Among them, the indicators of each factor of Eq. (3) are illustrated in Table 1.

Table 1. Indicator representation of influencing factors

Impact Factors（IF）	Symbols	Variable quantities
Population size effect	P	$\Delta P = \sum_{ij} \frac{E_{ij,t} - E_{ij,0}}{\ln E_{ij,t} - \ln E_{ij,0}} \cdot \ln \frac{P_{i,t}}{P_{i,0}}$
Urbanization level effect	$\rho = \frac{P_i}{P}$	$\Delta \rho = \sum_{ij} \frac{E_{ij,t} - E_{ij,0}}{\ln E_{ij,t} - \ln E_{ij,0}} \cdot \ln \frac{\rho_{i,t}}{\rho_{i,0}}$
Economic development effect	$g = \frac{G_i}{P_i}$	$\Delta g = \sum_{ij} \frac{E_{ij,t} - E_{ij,0}}{\ln E_{ij,t} - \ln E_{ij,0}} \cdot \ln \frac{g_{i,t}}{g_{i,0}}$
Industry level effect	$q = \frac{G_i}{P_i}$	$\Delta q = \sum_{ij} \frac{E_{ij,t} - E_{ij,0}}{\ln E_{ij,t} - \ln E_{ij,0}} \cdot \ln \frac{q_{i,t}}{q_{i,0}}$
Energy intensity effect	$c = \frac{E_i}{Q_i}$	$\Delta c = \sum_{ij} \frac{E_{ij,t} - E_{ij,0}}{\ln E_{ij,t} - \ln E_{ij,0}} \cdot \ln \frac{c_{i,t}}{c_{i,0}}$
Energy structure effect	$e = \frac{E_{ij}}{E_i}$	$\Delta e = \sum_{ij} \frac{E_{ij,t} - E_{ij,0}}{\ln E_{ij,t} - \ln E_{ij,0}} \cdot \ln \frac{e_{i,t}}{e_{i,0}}$

3.2 Data Sources and Data Processing

This paper takes nine cities of the Pearl River Delta as the study area, and the data used in the calculations are all from the statistical yearbooks of each city in the Guangdong Provincial Statistical Information Network.

3.2.1 Energy structure data processing. For Δe, the natural gas consumption data of Jiangmen and Zhaoqing are not available, so they cannot be included in the empirical analysis, which means the natural gas shares of the two cities on the energy structure were not included.

3.2.2 GDP data processing. For G_i, considering the high urbanization rate in the PRD region and the availability of data, only the impact of urban GDP was considered in the empirical analysis. In addition, all the indicators related to “GDP” in this paper have been deflated.

4 Results and Discussion

The total energy consumption of nine cities in the PRD region during 2014-2021 was calculated by factor decomposition through LMDI decomposition method, and the decomposition results were obtained as shown in Table 2.

Table 2. Results of factor decomposition of total energy consumption in the PRD region (2014-2021）

Year	Population size (million tce)	Urbanization level (million tce)	Economic development (million tce)	Industry level (million tce)	Energy intensity (million tce)	Energy structure (million tce)
2014-2015	454.965	96.437	789.348	-350.355	-616.299	-1181.736
2015-2016	502.304	68.680	959.747	-378.682	-534.349	-3113.721
2016-2017	632.737	53.340	1106.500	-1353.963	368.206	6119.846
2017-2018	621.797	370.182	345.943	-813.406	-64.525	-1200.652
2018-2019	474.513	-82.474	1255.638	-2839.318	315.350	-1437.336
2019-2020	473.848	303.084	-138.393	1435.651	-748.894	-876.224
2020-2021	235.729	84.873	2151.331	335.319	-1796.713	1151.463

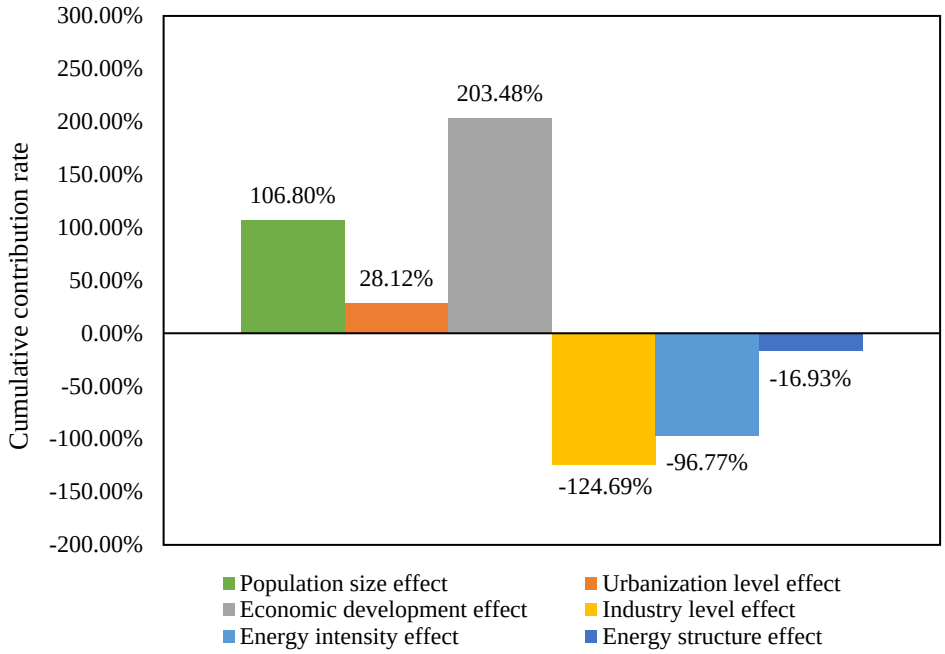

Figure 1. The cumulative contribution of the effect with each factor

To visualize the influence degree and direction of various factors on energy consumption, the cumulative contribution of each factor to energy consumption is calculated in this paper and

made into Figure 1 to see the effect of their influence on the total energy consumption in the PRD region.

Combining Table 2 and Figure 1, it can be seen that population size, urbanization level, and economic development have positive effects on the total energy consumption in the PRD region, among which the pulling effect of economic development is the strongest, with a contribution rate of 203.48% to the growth of energy consumption. The contribution of the population size ranks second at 106.80%, and the pulling effect of urbanization is slightly weaker than that of the economy and population, with a contribution rate of about 28%. In contrast, the level of industrial development, energy structure, and energy intensity curb the growth of energy consumption. The industrial level with a contribution of -124.69% has the strongest suppression on energy consumption, followed by the energy intensity with -96.77%. The energy structure effect is -16.93%. Further textual analysis and graphical analysis of the effect of each factor are presented below.

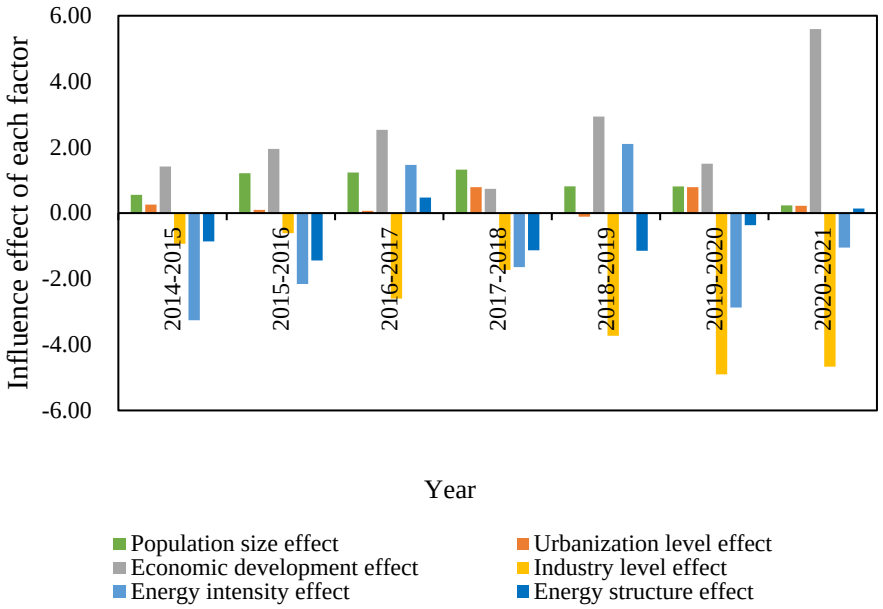

Figure 2. Yearly changes in the effects of various influencing factors (2014-2021)

4.1 Population size effect

The influence of the population size effect was stronger during 2016-2017, reaching 6.327 million tce. The reason above may be the impact caused by the priority introduction of a series of preferential policies for talents in the first-tier cities in the PRD region, mainly in Guangzhou, at the end of 2015. The purpose of preferential policies for talents is to attract advanced talents to settle in the region and help the construction of regional modern industries, of which the representative "1+4" document covers the benefits of talent incentives, talent green cards, and other aspects of the household. In addition, more importantly, maybe the impact of the promotion of the two-child policy. There was a small peak of rising fertility in

2017-2018, so the pull of the population size effect was more obvious in that annual phase. Subsequently, changes in social attitudes towards marriage and childbearing have led to a decline in fertility rates, thus slowly reducing the contribution of the population size effect to energy consumption.

4.2 Urbanization level effect

The urbanization effect contributes to the growth of energy consumption. The accelerated urbanization process led to a rise in energy consumption of 3.718 million tce in 2017-2018, which is three times higher than the contribution value in 2014. According to the Statistics Bureau of Guangdong Province, the number of urban population in the PRD region reached 50.897 million during 2018, and the urbanization rate rose from 71% to 86% in 2000, so it can be seen that the urbanization effect in that period contributed significantly. In 2019, the pull on energy consumption during the continued deepening of urbanization began to wane. From the perspective of sustainable development in the urban economy, this feature may slow down the growth rate of energy consumption and continue the cycle of urban energy reserves, while the urbanization of second-tier and third-tier cities such as Zhaoqing, Huizhou, and Jiangmen can be accelerated to improve the living standards and economic conditions of people in these regions.

4.3 Economic Development Effect

Economic development has a strong role in promoting total energy consumption. The positive effect of economic growth continued to climb from 2014-2017, driving energy consumption up by 17.490 million tce in 2014-2016. The incentive effect fell back slightly in 2018, but by the period of 2020-2021, the contribution of economic growth to energy consumption once again increased, pulling total energy consumption up by 21.513 million tce. The development of the economy is related to the use of energy. And the growth of energy consumption means that its support to the economy is strengthened, and the higher the degree of economic development, the more robust the energy demand. The economy of the PRD region has shown a strong development in recent years, so the total amount of energy used for national production and living consumption will increase accordingly to meet the social and economic development.

4.4 Industry level effect

The industry level has a strong inhibitory effect on total energy consumption. From 2014 to 2019, the increase in industry level continuously led to a decrease in energy consumption. From 2014-2018, the industry level reduced total energy consumption by a total of 28.964 million tce. By the end of 2019, the suppressive effect of the industry level was further strengthened, controlling the growth of 28.393 million tce in 2018-2019 alone. With the continuous development of society, the optimization and adjustment of industrial structure, and the upgrading and renewal of industrial technology, the production side will pursue more high-quality and high-efficiency utilization of energy, so with the continuous upgrading of technology, the energy consumption in industrial production will change in the direction of energy conservation, high efficiency, recyclability, and reuse.

4.5 Energy intensity effect

The energy intensity mainly has a suppressive effect on total energy consumption. From the factor decomposition results in Table 2 and the cumulative contribution rate in Figure 1, the energy intensity effect in the PRD region only pulled up energy consumption of 6.835 million tce between 2014 and 2021, but inhibits the increase in consumption of 37.608 million tce, with a cumulative contribution rate of -96.77% over the eight years. By optimizing the industrial structure, the PRD region is gradually reducing the intensity of energy use in the industry and gradually building an energy supply system with new energy, tilting advanced materials, advanced equipment, and new energy to new technology industries, and improving energy use efficiency and reducing product energy consumption.

4.6 Energy structure effect

The effect of the energy structure on energy consumption generally shows alternating promoting and inhibiting effects. For example, in 2016-2017, the pulling effect of energy structure was more pronounced, promoting a rise in energy consumption by 61.198 million tce. However, in terms of the cumulative contribution, the negative effect of energy structure is stronger. Due to the national “double carbon” target and the policy of local governments to actively develop clean energy, the influence of energy structure on energy consumption in the PRD region was slowly weakening. Since 2020, the positive contribution of energy structure has decreased from 61.198 million tce in 2016 to 8.762 million tce. The clean energy transition played an important role in the above situation. In the future, as the proportion of traditional energy sources such as coal and LPG in the energy structure decreases, the application of electricity and other new energy sources will become a new growth point for energy consumption.

5 Conclusion

In summary, it can be concluded that the factors that have a greater impact on the growth of energy consumption in the PRD region are economic development, industry level, population size, and energy intensity. Among them, economic development and population size have a positive pull on energy consumption. While the energy intensity and industry factors have a negative inhibition. Thus, economic development continues to be a major force in the growth of energy consumption. The population size effect is weakening year by year with the implementation of the new population policy and the improvement of residents' energy consumption concept in recent years. Energy intensity is the most significant inhibitor of energy consumption in the PRD region, and one of the important branches of the energy consumption structure is industry. That means the improvement of energy efficiency has made some contribution to slowing down energy losses, with the energy intensity of industry in the PRD region had been greatly reduced. Though the inhibitory effect of energy structure is not as significant as the energy intensity, optimizing the energy structure and trying to control the excessive growth of energy consumption remains a major way to reform energy utilization in the PRD region in the future.

6 Recommendation

6.1 Promote green transformation of energy and improve energy governance

The government should implement the priority strategy of energy conservation, improve the dual control system of energy consumption, focus on the regulation of high energy consumption and high pollution industries, and implement carbon reduction and energy saving programs in key energy-using industries such as construction, industry, and transportation. At the same time, the government should increase the support role of non-fossil energy development and utilization in carbon reduction on the supply side, and give full play to the leading role of economic and social transformation and upgrading in carbon reduction on the consumption side. Second, we could improve the energy governance systems, develop energy standards, standardize the construction of energy statistics and measurement system, raise the threshold of access to the energy industry, further deepen the reform of "management and administration"[3], and improve the business environment of the energy market.

6.2 Improving regional energy and industrial structure, accelerating energy saving and environmental protection of industrial technology

The industries should actively develop new energy sources and continuously optimize the industrial and energy structure. The government should create corresponding special funds to support industrial transformation and upgrading, use market-based means to activate corporate demand for green energy and improve the trading mechanism that facilitates the priority use of renewable energy. Accelerating the construction of offshore wind energy, nuclear energy, and other clean energy projects, improving the use of nuclear energy, gas energy, hydro energy, wind energy, solar energy and biomass energy and other clean energy, so that the energy structure could change towards a clean and environmentally friendly[14], diversified and high-quality direction, and enhance the structural effect on the slowdown of energy consumption growth.

6.3 Implementing population policy, improving the quality of the population, and promoting energy-saving and environment-friendly consumerism

We should improve the quality of the population, correctly guide the new urbanization process to avoid energy crises, and ensure the security of the energy supply. In addition, while the living and consumption level of residents in the PRD region is increasing, we should actively advocate a frugal and energy-saving lifestyle at the social level, guiding people to establish a frugal consumption concept, enhance residents' recognition of the concept of low-carbon living, energy conservation, and environmental protection, to prompt an increase in low-carbon consumption, thus causing a green transformation from the consumption side to the production side.

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