The Key Factors Influencing the Decline of Carbon Emission Intensity in Low-Carbon Cities and Countermeasure Research—A Case of Fuzhou, Jiangxi

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Abstract. Carbon emission intensity is an important indicator to evaluate the urban development level. Taking Fuzhou, a low-carbon pilot city of China in Jiangxi Province as an example, based on the current levels of energy consumption and carbon emissions, this paper proposes the concept of “the marginal effect of carbon emission intensity” and analyzes the eleven factors influencing the decline of carbon emission intensity in low-carbon cities. Results show that the rise of carbon emissions in industrial sectors are the main reason for the abnormal increase in the carbon emission amount and intensity of Fuzhou, and that the coal consumption level, GDP and electricity sent out to other cities are the key factors influencing the decline of carbon emission intensity. Based on the analysis, countermeasures and suggestions are put forward as a reference for the municipal government in the construction of low-carbon cities.

1. Introduction
At present, global warming has seriously threatened the sustainable development of mankind [1]. At the 75th Session of the United Nations General Assembly, Xi Jinping, President of the People’s Republic of China, claimed that China aims to have carbon emissions peak before 2030 and achieve carbon neutrality before 2060. It has an important leading role in accelerating the low-carbon transformation and the implementation of ecological civilization construction strategy in China [2,3]. As one of the third batch of low-carbon pilot cities in China, Fuzhou is of great representativeness in the process of low-carbon construction. After years of efforts, Fuzhou has made positive progress in the construction of low-carbon industry, the development of low-carbon transportation and the improvement of carbon sink capability, forming a low-carbon development model with regional characteristics. Carbon emission intensity is an important indicator to evaluate the urban low-carbon development level. In recent years, with the rapid development of economy and society, the carbon dioxide emissions caused by energy consumption increase rapidly in Fuzhou, and the carbon emission intensity increases instead of decreasing, which brings a severe challenge to the work of coping with climate change under the new development concept and the construction of national low-carbon pilots. In the new situation aiming at having carbon emissions peak before 2030 and achieving carbon neutrality before 2060, it has become practical problems for Fuzhou to find out the key factors influencing the decline of carbon emission intensity, to put forward the countermeasures beneficial to the decline and to reach the peak of carbon emissions as soon as possible.
2. General situation of Fuzhou
Fuzhou is located in the east of Jiangxi Province, China, and is a strategic hinterland bordering the Yangtze River Delta, Pearl River Delta and Southeast Fujian Delta. Its total area is 18800 square kilometers, with the resident population of 4.06 million, and 66.3% of the area is covered with forest. It is a demonstration city of National ecological civilization pilot zone. During the 13th Five-Year Plan period, Fuzhou’s GDP maintained a steady upward trend, increasing for 99.23 billion yuan in 2015 to 142.21 billion yuan in 2019, with an average annual growth of about 8%. As Datang International Power Plant in Fuzhou was put into operation in 2016, the total energy consumption of Fuzhou increased significantly from 2.72 million tce in 2015 to 5.33 million tce in 2019, and the proportion of coal consumption in the total energy consumption also increased rapidly from 39.6% in 2015 to 75.9% in 2019, resulting in the great pressure of fulfilling the carbon emission reduction task for national low-carbon pilot cities during the 14th Five-Year Plan period.

3. Current situation of carbon dioxide emissions in Fuzhou

3.1. Current situation of carbon dioxide emissions and carbon emission intensity
From 2015 to 2019, the total carbon dioxide emissions of Fuzhou showed a rapid growth trend, rising from 7.53 million tCO$_2$ in 2015 to 11.98 million tCO$_2$ in 2019, with a growth rate of 59.05%. The carbon emission intensity increased by 12.7% in three years, from 7.587 tCO$_2$ per thousand yuan in 2015 to 8.552 tCO$_2$ per thousand yuan in 2018. The carbon emission intensity did not decline until 2019, but it was still 10.99% higher than that in 2015, as shown in Figure 1.

![Figure 1. Total CO2 emissions and carbon emission intensity of Fuzhou from 2015 to 2019](image)

3.2. Characteristics of carbon dioxide emissions
From the perspective of carbon dioxide emission structure, coal-fired carbon dioxide emission is the main emission source, followed by oil-fired emission, as shown in Table 1. Since 2015, carbon dioxide emissions by coal combustion have increased significantly from 2.86 million tCO$_2$ to 12.01 million tCO$_2$ in 2019, with the increase rate of 319.47%. The carbon dioxide emissions from oil and gas are relatively stable with a slow rising trend.

Since 2016, Fuzhou’s electricity started to be sent out to other cities rather than transferred in. In 2015, the carbon dioxide emissions generated by electricity transferred in from other cities was 2.80
million tCO$_2$. In 2019, the carbon dioxide emissions generated by electricity sent out was 2.45 million tCO$_2$, with a change of 5.25 million tCO$_2$.

Table 1. CO2 emissions of Fuzhou from 2015 to 2019

| Items                                             | 2015   | 2016   | 2017   | 2018   | 2019   |
|---------------------------------------------------|--------|--------|--------|--------|--------|
| Coal combustion CO$_2$ emissions / kt              | 2863.2 | 8873.8 | 11140.6| 11425.0| 12010.4|
| Oil combustion CO$_2$ emissions / kt               | 1769.9 | 1786.8 | 1794.1 | 2050.4 | 2104.2 |
| Gas combustion CO$_2$ emissions / kt               | 95.6   | 123.9  | 140.3  | 184.5  | 305.4  |
| CO$_2$ emissions of electricity transferred in from other cities / kt | 2800.4 | 0.0    | 0.0    | 0.0    | 0.0    |
| CO$_2$ emissions of electricity sent out to other cities / kt | 0.0    | -2124.2| -2960.3| -2389.8| -2445.0|

From the perspective of sectoral carbon dioxide emissions, considering that when the nation and Jiangxi Province assess the target of local carbon emission intensity decline, carbon dioxide emissions refer to those generated by fossil fuel consumption and by electricity transferred in and sent out [4]. However, the carbon dioxide emissions generated by electricity transferred in and sent out are difficult to be separated into sectors, and the emissions of sectors are calculated according to the actual consumption of coal, oil, natural gas and electricity, without deducting the emissions generated by electricity export. The total carbon dioxide emissions and sectoral emissions are calculated by different methods, so the sum of sectoral emissions will be larger than the total amount mentioned above.

From 2015 to 2019, carbon dioxide emissions of industrial sectors in Fuzhou increased fastest, with an increase of 254.36% in four years (Table 2). Moreover, carbon dioxide emissions of industrial sectors accounted for a large proportion of the total emissions, reaching 74.06% in 2019, which was the main reason for the rapid rise of total carbon dioxide emissions in Fuzhou. The carbon dioxide emissions of agricultural sector, transport sector and construction sector are relatively stable. The carbon dioxide emissions of residential consumption are rising steadily, increasing by 34.14% from 2015 to 2019; the carbon dioxide emissions of service industry are low in amount, but it is rising rapidly, with an increase of 161.56% in 2019 compared to 2015.

In industrial sectors (Table 3), the carbon dioxide emissions of manufacture of textile, wearing apparels and accessories went down during 2015-2019, and the emissions of other industries showed an upward trend. The emissions of manufacture of paper and paper product, manufacture of machinery and other industries increased rapidly, with the growth rate of 85.15%, 52.84% and 90.97% respectively from 2015 to 2019. The largest increase of emissions was in the manufacture of power, from zero in 2015 to 8.79 million tCO$_2$ in 2019. It accounted for 59.13% of the total emissions of industrial sectors, and was the most direct reason for the rapid growth of total emissions of Fuzhou.

Table 2. Sectoral CO2 emissions of Fuzhou from 2015 to 2019 (tce)

| Sectors           | 2015    | 2016    | 2017    | 2018    | 2019    |
|-------------------|---------|---------|---------|---------|---------|
| Industry          | 4194.4  | 10427.3 | 12936.8 | 13793.0 | 14863.4 |
| Construction      | 138.3   | 128.9   | 97.5    | 116.1   | 136.7   |
| Agriculture       | 260.7   | 244.8   | 316.4   | 225.0   | 216.0   |
| Transport         | 958.8   | 984.9   | 1026.5  | 765.0   | 1055.0  |
| Service           | 611.9   | 701.6   | 759.8   | 1655.0  | 1600.4  |
| Household Consumption | 1637.9  | 1868.9  | 1974.0  | 2115.5  | 2197.2  |
Table 3. Industrial CO2 emissions of Fuzhou from 2015 to 2019 (tce)

| Industrial Sectors                          | 2015    | 2016    | 2017    | 2018    | 2019    |
|--------------------------------------------|---------|---------|---------|---------|---------|
| Production of Electricity                  | 0.0     | 6020.6  | 7912.4  | 8317.0  | 8788.4  |
| Manufacture of Textile                     | 314.0   | 455.4   | 368.7   | 433.6   | 378.9   |
| Manufacture of Paper and Paper Products    | 204.7   | 223.5   | 241.1   | 1147.2  | 1218.9  |
| Chemical Industry                          | 990.7   | 870.5   | 943.1   | 1174.2  | 1218.9  |
| Manufacture of Non-Metallic Mineral Products| 1028.3  | 976.0   | 1033.4  | 1119.0  | 1097.7  |
| Non-Ferrous Metals                         | 303.7   | 372.8   | 417.5   | 439.9   | 340.9   |
| Manufacture of Machinery                   | 349.7   | 373.6   | 418.6   | 688.7   | 884.2   |
| Other Industries                           | 1003.4  | 1134.9  | 1602.0  | 1422.5  | 1916.2  |

4. Analysis on the factors influencing the decline of carbon emission intensity

In order to solve the problem of abnormal increase in carbon emission intensity of Fuzhou and realize the green and low-carbon development of the city, it is urgent to find out the key factors influencing the decline of carbon emission intensity. This paper uses the theory of "marginal effect" in economics [5-7] to analyze the influencing factors. Marginal effect refers to the possible effect of one factor’s change by one unit and its influence on people's decision-making under other conditions unchanged. Extending the concept of marginal effect to carbon emission intensity, "marginal effect of carbon emission intensity" can be calculated to estimate how the change of each single factor influences carbon emission intensity.

4.1. Calculation of carbon emissions

Carbon dioxide emissions refer to the carbon dioxide emissions generated by fossil fuel consumption and by the production of the electricity transferred in from and sent out to other cities. It is calculated by Eq. (1):

\[ E_{CO2} = E_{coal} + E_{oil} + E_{gas} + E_{ei} - E_{eo} \]  

where:
- \( E_{CO2} \) is the total emission of the city (tCO\textsubscript{2})
- \( E_{coal} \) is the emission of coal combustion (tCO\textsubscript{2})
- \( E_{oil} \) is the emission of oil combustion (tCO\textsubscript{2})
- \( E_{gas} \) is the emission of gas combustion (tCO\textsubscript{2})
- \( E_{ei} \) is the emission of electricity transferred in from other cites (tCO\textsubscript{2})
- \( E_{eo} \) is the emission of electricity sent out to other cities (tCO\textsubscript{2})

4.2. Calculation of carbon emission intensity

Carbon emission intensity refers to the total carbon dioxide emissions divided by the current year's GDP (at comparable prices in the base year). It is calculated by Eq. (2):

\[ EI_{CO2} = \frac{E_{CO2}}{GDP} = \frac{A_{coal} \times F_{coal} + A_{oil} \times F_{oil} + A_{gas} \times F_{gas} + A_{ei} \times F_{ei} - A_{eo} \times F_{eo}}{GDP} \]  

where:
- \( A_{coal} \) is the coal consumption of the year (tce)
- \( A_{oil} \) is the oil consumption of the year (tce)
- \( A_{gas} \) is the gas consumption of the year (tce)
- \( A_{ei} \) is the electricity transferred in from other cities of the year (kWh)
- \( A_{eo} \) is the electricity sent out to other cities of the year (kWh)
- \( F_{coal} \) is the comprehensive emission factor of coal combustion (tCO\textsubscript{2}/tce)
- \( F_{oil} \) is the comprehensive emission factor of oil combustion (tCO\textsubscript{2}/tce)
$F_{\text{gas}}$ is the comprehensive emission factor of gas combustion (tCO$_2$/tce)

$F_{\text{ei}}$ is the comprehensive emission factor of electricity transferred in from other cities (kgCO$_2$/kWh)

$F_{\text{eo}}$ is the comprehensive emission factor of electricity sent out to other cities (kgCO$_2$/kWh)

GD$P$ is the local gross domestic product of the year (yuan)

4.3. Calculation of carbon emission intensity marginal effect

This paper takes the year 2018 with the highest carbon emission intensity as the subject, and calculated the marginal effects by partial derivative. The Equations are as follows.

Marginal effect of coal consumption $I_{A_{\text{coal}}}$

$$I_{A_{\text{coal}}} = \frac{\partial E_{\text{CO}_2}}{\partial A_{\text{coal}}} \times \frac{A_{\text{coal}}}{E_{\text{CO}_2}} = \frac{F_{\text{coal}}}{GD\text{P}} \times \frac{A_{\text{coal}}}{E_{\text{CO}_2}}.$$  

Marginal effect of oil consumption $I_{A_{\text{oil}}}$

$$I_{A_{\text{oil}}} = \frac{\partial E_{\text{CO}_2}}{\partial A_{\text{oil}}} \times \frac{A_{\text{oil}}}{E_{\text{CO}_2}} = \frac{F_{\text{oil}}}{GD\text{P}} \times \frac{A_{\text{oil}}}{E_{\text{CO}_2}}.$$  

Marginal effect of gas consumption $I_{A_{\text{gas}}}$

$$I_{A_{\text{gas}}} = \frac{\partial E_{\text{CO}_2}}{\partial A_{\text{gas}}} \times \frac{A_{\text{gas}}}{E_{\text{CO}_2}} = \frac{F_{\text{gas}}}{GD\text{P}} \times \frac{A_{\text{gas}}}{E_{\text{CO}_2}}.$$  

Marginal effect of electricity transferred in from other cities $I_{A_{\text{ei}}}$

$$I_{A_{\text{ei}}} = \frac{\partial E_{\text{CO}_2}}{\partial A_{\text{ei}}} \times \frac{A_{\text{ei}}}{E_{\text{CO}_2}} = \frac{F_{\text{ei}}}{GD\text{P}} \times \frac{A_{\text{ei}}}{E_{\text{CO}_2}}.$$  

Marginal effect of electricity sent out to other cities $I_{A_{\text{eo}}}$

$$I_{A_{\text{eo}}} = \frac{\partial E_{\text{CO}_2}}{\partial A_{\text{eo}}} \times \frac{A_{\text{eo}}}{E_{\text{CO}_2}} = -\frac{F_{\text{eo}}}{GD\text{P}} \times \frac{A_{\text{eo}}}{E_{\text{CO}_2}}.$$  

Marginal effect of comprehensive emission factor of coal combustion $I_{E_{\text{coal}}}$

$$I_{E_{\text{coal}}} = \frac{\partial E_{\text{CO}_2}}{\partial E_{\text{coal}}} \times \frac{E_{\text{coal}}}{E_{\text{CO}_2}} = \frac{F_{\text{coal}}}{GD\text{P}} \times \frac{E_{\text{coal}}}{E_{\text{CO}_2}}.$$  

Marginal effect of comprehensive emission factor of oil combustion $I_{E_{\text{oil}}}$

$$I_{E_{\text{oil}}} = \frac{\partial E_{\text{CO}_2}}{\partial E_{\text{oil}}} \times \frac{E_{\text{oil}}}{E_{\text{CO}_2}} = \frac{F_{\text{oil}}}{GD\text{P}} \times \frac{E_{\text{oil}}}{E_{\text{CO}_2}}.$$  

Marginal effect of comprehensive emission factor of gas combustion $I_{E_{\text{gas}}}$

$$I_{E_{\text{gas}}} = \frac{\partial E_{\text{CO}_2}}{\partial E_{\text{gas}}} \times \frac{E_{\text{gas}}}{E_{\text{CO}_2}} = \frac{F_{\text{gas}}}{GD\text{P}} \times \frac{E_{\text{gas}}}{E_{\text{CO}_2}}.$$  

Marginal effect of comprehensive emission factor of electricity transferred in from other cities $I_{E_{\text{ei}}}$

$$I_{E_{\text{ei}}} = \frac{\partial E_{\text{CO}_2}}{\partial E_{\text{ei}}} \times \frac{E_{\text{ei}}}{E_{\text{CO}_2}} = \frac{F_{\text{ei}}}{GD\text{P}} \times \frac{E_{\text{ei}}}{E_{\text{CO}_2}}.$$  

Marginal effect of comprehensive emission factor of electricity sent out to other cities $I_{E_{\text{eo}}}$

$$I_{E_{\text{eo}}} = \frac{\partial E_{\text{CO}_2}}{\partial E_{\text{eo}}} \times \frac{E_{\text{eo}}}{E_{\text{CO}_2}} = \frac{F_{\text{eo}}}{GD\text{P}} \times \frac{E_{\text{eo}}}{E_{\text{CO}_2}}.$$  

Marginal effect of GDP $I_{GD\text{P}}$

$$I_{GD\text{P}} = \frac{\partial E_{\text{CO}_2}}{\partial GD\text{P}} \times \frac{GD\text{P}}{E_{\text{CO}_2}} = -\frac{E_{\text{CO}_2}}{GD\text{P}^2} \times \frac{GD\text{P}}{E_{\text{CO}_2}}.$$  

The marginal effects are calculated in relative quantities, and reflect the percentage of the change in carbon emission intensity caused by every 1% change of influencing factors. For example, the marginal effect of oil consumption on carbon emission intensity is 0.19%, which means every 1% increase in oil consumption will lead to the increase of carbon emission intensity by 0.19%. A negative marginal effect means the increase of influencing factors will result in the decrease of carbon emission intensity. Figure 2 shows that the influencing factors of the same type have the same marginal effects. The coal consumption and the comprehensive emission factor of coal combustion have the largest marginal effect, their marginal effects on the carbon emission intensity are both 1.07%. The second is GDP with the marginal effect of 0.99%, and the third is electricity sent out to other cities along with its comprehensive emission factor with the marginal effect of 0.22% in absolute value. The marginal effects of electricity transferred in and the comprehensive emission factor of it are 0 because there was no electricity transferred in from other cities in 2018 in Fuzhou.
4.4. Conclusion
According to the calculation, coal consumption level, GDP, the emission factor of electricity transferred in and sent out are the most decisive factors for the decline of carbon emission intensity. As the comprehensive emission factor for coal combustion and electricity are based on the latest national data, it is difficult for municipal government to regulate. Therefore, coal consumption, GDP, and electricity sent out to other cities are the most critical factors affecting the decline of carbon emission intensity. Fuzhou can effectively reduce the carbon emission intensity by controlling the total coal consumption, establishing an industrial system characterized by low carbon emission, and improving the electricity generation efficiency and energy efficiency level of coal-combustion power units.

5. Countermeasures and suggestions

5.1. Strengthen the control of carbon emission and the decomposition of emission intensity
(1) Strengthen organization and management. It is suggested to strengthen the leading group on the national low-carbon pilot construction and the guidance of the leading group on emission reduction and climate change. An interdepartmental cooperation mechanism, led by Fuzhou Municipal Ecology and Environment Bureau, together with Municipal Development and Reform Commission, Municipal Commission of Industry and Information Technology, the Municipal Bureau of statistics and other relevant departments, should be established to carry out the work of total carbon emission control, decomposition and implementation of the tasks of carbon emission intensity reduction and carbon emissions peak. All departments should take charge of the implementation according to the division of responsibilities.

(2) Strengthen the implementation of tasks and responsibilities. It is suggested to take the total carbon emission control and carbon emission intensity reduction targets into the comprehensive evaluation and performance appraisal system of economic and social development, and the constraints should be strengthened. The assessment for the implementation of the target of total carbon emission control and carbon emission intensity reduction in cities, counties and districts should be formulated with regular supervision and assessment.

5.2. Establish a low-carbon industrial system and increase the proportion of green GDP
Taking the optimization of economic structure and technological innovation as driving forces, traditional industries should be transformed and upgraded and the cultivation of strategic emerging industries should be accelerated to establish an industrial system characterized by low-carbon emissions. Taking
the digital economy as the guide and advanced manufacturing industry as the focus, the strategic emerging industries such as biomedicine, new energy vehicles, green food processing, energy conservation and environmental protection, new materials and new generation of information technology industries should be cultivated and expanded to realize the multiplication of strategic emerging industries, the improvement of economic quality and core competitiveness, and the increase in the proportion of green GDP. Characteristic industrial clusters with comparative advantages and strong competitiveness should be cultivated, and the leading enterprises and branded products should be sponsored to speed up the pace of coming to the market. The modern service industry should be vigorously developed. The producer service industry should be specialized and extended towards high-end value chain. The life service industry should be upgraded to high quality and diversity. The modern service industry should be integrated with advanced manufacturing industry and modern agriculture.

5.3. Adjust energy consumption structure and strictly control coal consumption
(1) Total energy consumption and coal consumption should be controlled. In 2019, the proportion of coal consumption in total energy consumption of Fuzhou is close to 85%, which is at a high level. Therefore, it is necessary to speed up the adjustment of energy consumption structure, implement total energy consumption control and total coal consumption control, and continuously reduce the proportion of coal consumption. The electricity generation efficiency and energy consumption efficiency level of existing coal-combustion power units should be improved, the amount of electricity sent to other cities should be increased. It is also suggested to promote central heating, shut down coal-fired heating boilers of enterprises, improve coal utilization efficiency, and reduce carbon emission intensity of unit energy consumption.

(2) The use of clean energy should be vigorously promoted. The application of renewable energies, such as solar energy, biomass energy and wind energy, should be promoted, and their proportion in energy generation and consumption should be raised. It is also suggested to promote the replacement of coal with natural gas and electricity, and to establish natural distributed energy system or central heating system of natural gas in some qualified industrial parks and enterprises. In urban areas, the government should promote the construction of natural gas pipeline networks to basically realize the full coverage of natural gas, push forward the construction of natural gas filling stations to promote the use of gas taxis and buses, promote the application of electric vehicles, strengthen the construction of electric vehicle charging infrastructure, and actively promote electric buses, so that full coverage of electric buses in urban areas can be realized.

5.4. Implement the carbon emission double control system and trading system
(1) Implement the carbon emission double control system. Innovate the management mechanism of carbon emissions and accelerate the implementation of the double control system of total carbon emission and carbon emission intensity. Based on the double control target, taking into consideration the economic development level, industrial structure, energy consumption and carbon emission status, and the technical level of key industries of each county and district, the "double control" goal of total carbon emission and carbon emission intensity should be decomposed to each county and district, and each county and district must complete the double control goal according to the assigned tasks.

(2) Implement the carbon emission trading system. According to the overall deployment of the nation and Jiangxi Province, municipal government should promote the carbon emission trading of key enterprises in the region, determine the subject of carbon emission trading, carry out annual carbon emission monitoring, reporting and third-party verification for key enterprises, strengthen the management of key emission enterprises with comprehensive energy consumption over 10 thousand tce, cooperate with the provincial authorities to carry out carbon emission quota allocation, and study and analyze the key issues such as quota allocation scheme, total amount and allocation method, so as to ensure that the quota of the whole city is reasonable and appropriate.
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