Research on Short-Term Prediction Method and Application of Energy Consumption in Guangzhou and its Districts

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Abstract. Guangzhou’s energy consumption accounts for 24.9\% of the energy consumption of Guangdong-Hong Kong-Macao Greater Bay Area (GBA). The improvement of Guangzhou’s energy management system has a significant impact and exemplary role on the energy management of GBA. Therefore, Guangzhou needs annual, quarterly and monthly energy consumption prediction for the requirements of energy consumption control and establishment of refined energy management system. Meanwhile, due to the lack of historical data, it also needs a short-term prediction method of energy consumption with short cycle and small sample. The paper provided variety of city level prediction methods and all districts energy consumption prediction method to predict the energy consumption of Guangzhou in 2018. Then this paper verify the prediction methods, and apply them to the prediction of energy consumption in 2019 and 2020. The results show that in the case of short-term prediction and small data samples, we can use a variety of factors to predict the energy consumption by refining the data collection area. And the result of all districts energy consumption prediction method is closer to the actual value than that of other methods. However, there are some difficulties in data collection of districts. Thus, in order to establish an accurate short-term prediction method, it is also necessary to strengthen the combination of city and district level energy monitoring and management systems, and expands the channels for collection and summary of district level energy data. Finally, in the future, the prediction method can be applied to GBA after the establishment of unified energy information statistics system of each city in GBA.

1. Introduction

In order to implement the national energy strategic layout of “Four revolutions, One cooperation”, and ensure the safety of energy supply and accelerate the structural transformation of energy [1], Guangdong province has set a binding target of energy consumption annual growth of 2.3\% in the 13th five year plan for energy development [2]. So the future energy management objectives of GBA are to optimize the energy structure and layout, deepen the reform of energy management mechanism, and vigorously develop smart energy. Under the background of the “Internet +” development strategy promoted by the state, the Guangzhou development and Reform Commission has set up an energy management and auxiliary decision-making platform for Guangzhou. This makes Guangzhou’s smart energy management and supervision tools at the forefront of the GBA, and has an innovative and exemplary role in the energy management of the cities in the GBA.
Guangzhou is a city with massive energy consumption in GBA. In 2017, the energy consumption of Guangzhou accounted for 24.9% of the energy consumption of GBA. During the 12th Five Year Plan period, the energy consumption of Guangzhou increased by 3.6% annually (table 1). And Guangdong province issued the amount energy consumption control goal to Guangzhou during the 13th Five Year Plan period: by 2020, the energy consumption will be controlled within 6284-10ktee, with an average annual growth rate of 2.1% (China Southern Airlines and other central or provincial enterprises in Guangzhou and their key projects energy consumption are listed separately) [3]. Therefore, in order to achieve the energy consumption control goal of Guangzhou, Guangzhou needs to establish a refined energy management system and implement adjustment measures for energy consumption in advance. At the same time, the energy management system needs accurate short-term prediction of energy consumption, and looks for factors closely related to energy consumption in the prediction process. Besides, it also needs short-term prediction for each district with different energy consumption characteristics to realize the refined management of energy consumption.

| Energy consumption data of Guangzhou from 2010 to 2017. |
|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|
|                 | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   |
| Energy consumption (10ktee) | 4776   | 5013   | 5163   | 5334   | 5496   | 5689   | 5853   | 5962   |
| Energy consumption growth rate (%) | 5.0    | 3.0    | 3.3    | 3.1    | 3.5    | 2.9    | 1.9    |

The short-term prediction focuses on the fluctuation of variables in a short period of time and the prediction accuracy of one or two period predicted result in the future. The prediction factors and relationship of factors should be dynamic rather than long-term equilibrium relations. Therefore, when selecting data, we should select the data in a short period of time and timely discard the older data and add new data. The period of 5-10 years is short compared with the huge economy of Guangzhou, and the annual statistics of energy data results in less time nodes and small data samples. So this paper uses 2010-2017 energy related data of Guangzhou city to predict energy consumption. Based on the real data of short period and small sample, in order to provide an efficient, accurate and feasible prediction scheme of energy consumption, this paper will use the corresponding prediction methods to predict energy consumption from two angles. Then the paper analyzes the prediction results of each method, and gets a comprehensive prediction scheme.

First of all, in terms of influencing factors, the factors that affect the energy consumption include population [4], GDP [5], industrial structure, technological progress, energy price, etc. According to the characteristics of large population changes in Guangzhou, the paper mainly considers the impact of population on energy consumption. Zhang [6] studied the impact of population on energy consumption in China, Japan and South Korea, and found that population has a significant positive correlation with energy consumption in the three countries. Song et al. [7] concluded that the impact of population factors on energy consumption is greater than the economic development. These study show that it is reasonable to use population factors to predict energy consumption. Secondly, in the aspect of prediction methods, many scholars have conducted in-depth research on energy consumption prediction in the 1970s. Prediction methods are mainly divided into two categories [8]: First is time series analysis model, such as autoregressive integrated moving average model (ARIMA) [9] and grey model [10]. The second is the nonlinear prediction model. Support vector regression (SVR) model, back propagation (BP) neural network model and radial basis function (RBF) neural network are widely used in nonlinear prediction models. In the above mentioned methods, the nonlinear prediction often needs enough historical data to describe the nonlinear characteristics of variables. If the amount of data is too small, it is easy to over fit, resulting in high fitting accuracy of the model and poor actual prediction results, so it is not suitable to use the second type of model which is too complex. And in the time series analysis model, ARIMA model will further reduce the original data amount due to the prophase date prepare operation, which is not suitable for the case of small data in Guangzhou. However, the grey prediction model is more suitable for the situation of small amount of information.
and data in Guangzhou. In addition, there are combination model and scenario prediction and other methods. The combination model [11] may improve the accuracy after integrating multiple model results, while scenario prediction [12] is more suitable for long-term prediction. Finally, on the prediction scale, Liu et al. [13] predicted the energy consumption of China in 2020 based on the fixed base energy consumption elasticity coefficient method. And Xie et al. [14] used GM (1, 1) model to predict the energy consumption and structure of Jiangsu province. The prediction of the above study is based on the city level or above. But the characteristics of energy consumption prediction in Guangzhou are small sample and short prediction cycle, if the prediction is only made at the level of city, many factors cannot be considered, and the causes included in the prediction model are too few, which is not conducive to the prediction of the fluctuation of energy consumption and the causes of its formation. Therefore, this study attempts to expand the data from city level to district level, and increase the overall data amount, prediction subject and factors type under the same time span.

In conclusion, the energy consumption of Guangzhou is predicted from the following perspectives: First, from the perspective of population, the paper use population data to predict the energy consumption and analyze the characteristics of the prediction results. Second, in terms of prediction method, processing data to makes it more regular, and discusses its impact on the prediction results. Third, from the perspective of prediction level, the data amount of the city in the same period is extended to that of each district, and the influence of refining research unit on the prediction results is discussed. Finally, from the perspective of policy, one is to consider the relationship between the energy consumption of Guangzhou and Guangdong province, and the other considering the population policy impact on the population.

2. Research Methods and Data Sources

2.1. Technical Route

The prediction method used in this paper is shown in figure 1. Firstly, starting from the relatively simple linear trend prediction, then gradually increase the factors and refine the research unit, build the model from the two dimensions of data level and the factors. Then compare and discuss the differences, accuracy and practicality between the prediction methods. Finally, the results of different methods are combined.

![Figure 1. Structural charts of prediction methods.](image)

2.2. Guangdong Province Energy Consumption Back-Stepping Method

This method is based on the fact that the energy consumption in Guangzhou accounts for a relatively stable share of that in Guangdong province in recent years. The specific methods are as follows:
According to the energy consumption of Guangdong province over the years, the unitary linear regression is carried out. Because the cardinal number of Guangdong province is big, its energy consumption growth is relatively stable and linear. The prediction values of energy consumption in 2018 and 2019 in Guangdong province are obtained by time linear regression. Here, the average energy consumption ratio of Guangzhou in 2010-2017 to the total amount of Guangdong province is 19.19% for prediction. According to equation (1), the prediction results of energy consumption in Guangzhou are obtained.

\[
\hat{E}_t = \overline{PE}_t \times 0.1919
\]

where, \(\hat{E}_t\) represent the predicted energy consumption of Guangzhou in year \(t\). \(\overline{PE}_t\) is the predicted energy consumption of Guangdong province in year \(t, t = \{2017, 2018\}\).

2.3. Grey Model

According to the grey theory, the known data series are generated into dynamic or non dynamic white modules according to some rules, and the internal rules are explored or searched from the disordered original data. Then the grey model is established to predict the future value. Grey model GM (1, 1) is to accumulate the original sequence and generate a new sequence with obvious regularity, then establish the first order differential equation and make the least square estimation. Lastly, the prediction value of the original series is reduced by subtraction.

Let equal interval time series \(x^0\) have \(n\) observations \(x^0 = \{x^0(1), x^0(2), \ldots, x^0(n)\}\), make one cumulative generation, that is, \(x^1(k) = \sum_{i=1}^{k} x^0(i)\), and get a sequence whose randomness is weakened \(x^1 = \{x^1(1), x^1(2), \ldots, x^1(n)\}\), let \(z^{(1)}\) be the mean sequence of \(x^{(1)}, z^{(1)}(k) = \frac{1}{2}[x^{(1)}(k) + x^{(1)}(k-1)]\), then \(z^{(1)} = \{z^{(1)}(1), z^{(1)}(2), \ldots, z^{(1)}(n)\}\). The model is as follows:

\[
\frac{dx^{(1)}}{dt} + ax^{(1)} = b
\]

where \(a\) is the development coefficient and \(b\) is the grey coefficient. The prediction model can be obtained by solving the differential equation:

\[
x^{(1)}(k) = \left[x^0(1) - \frac{b}{a}\right] e^{-a(k-1)} + \frac{b}{a} (k = 1, 2, 3 \ldots, n)
\]

(3)

\[
x^{(0)}(1) = x^{(1)}(1) = x^{(0)}(0)
\]

(4)

\[
x^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1) (k = 1, 2, \ldots, n)
\]

(5)

This paper used the gray prediction model to predict the energy consumption of the city and the energy consumption of each district in 2010-2017.

2.4. Per Capita Electricity Consumption Prediction Method

The per capita electricity consumption prediction method involves three factors: population, electricity consumption and energy consumption. The specific steps are as follows:

First, collect the population, electricity consumption and energy consumption data of Guangzhou City, which are recorded as \(P_i, EL_i, E_i\) respectively, representing the corresponding data of each year, where \(i\) is the corresponding year. Use the above data to calculate the per capita electricity consumption and the ratio of electricity consumption to energy consumption in each year, as shown in equations (6) and (7).

\[
ELP_i = \frac{EL_i}{P_i}
\]

(6)

\[
ELR_i = \frac{EL_i}{E_i}
\]

(7)

where \(ELP_i\) represent the per capita power consumption in year \(t\); \(ELR_i\) is the ratio of electricity
consumption to energy consumption in year \( t \). \( t =\{2010, 2011, \ldots, 2017\} \).

Secondly, the trend of per capita electricity consumption and the ratio of electricity consumption to energy consumption is predicted by linear regression. The predicted values \( \hat{\text{ELP}}_{2018} \), \( \hat{\text{ELR}}_{2018} \) are obtained respectively. According to the relevant Guangzhou city planning, the average growth rate of the permanent population is 400 thousands, and the 2018 prediction value \( \hat{\text{P}}_{2018} \) is obtained based on the 2017 population data. Finally, the predicted value of the energy consumption is obtained through the predicted population, per capita electricity consumption and the proportion of electricity consumption, as shown in equation (8).

\[
\hat{E}_t = \frac{\hat{\text{P}}_t \times \hat{\text{ELP}}_t}{\text{ELR}_t} \quad (8)
\]

where, \( \hat{E}_t \) is the predicted energy consumption of Guangzhou in \( t \) year, \( t =\{2018\} \).

2.5. Prediction Method of Relationship between Energy Consumption and Population

Figure 2 shows the growth rate of per capita energy consumption and population. It can be seen from the figure that there is a certain inverse relationship between the two growth rates. When the population growth is fast, the per capita energy consumption growth slows down, sometimes even becomes negative. Table 2 shows that the growth rate of per capita energy consumption in the current period is significantly negatively correlated with the growth rate of population in the current period, while the growth rate of population is not significantly correlated with the growth rate of energy consumption. So the current population growth only has little impact on the current growth of energy consumption. Then use the correlation analysis between the growth rate of population in the last period and the growth rate of energy consumption in the current period, the correlation is significant. Therefore, the impact of population on energy consumption lags behind. Based on this point of view, the following regression equations are constructed:

\[
\text{EI}_t = c_1 + c_2 \text{PI}_{t-1} + \mu_t \quad (9)
\]

where \( \text{EI}_t = \frac{E_t}{E_{t-1}} - 1 \) is the growth rate of energy consumption in the current period. \( \text{PI}_{t-1} = \frac{P_{t-1}}{P_{t-2}} - 1 \) is the population growth rate of the last period. \( c_1 \) is the intercept term, \( c_2 \) is the coefficient of independent variable, \( \mu_t \) is the random error term. \( t =\{2011, 2012, \ldots, 2017\} \).

After the regression equation is established, substitute \( \text{PI}_{2017} \) into the equation to get the predicted growth value of energy consumption \( \hat{\text{EI}}_{2018} \). Finally, the energy consumption prediction value \( \hat{E}_{2018} \) is obtained.

![Figure 2. Per capita energy consumption and population growth rate in Guangzhou.](image-url)
Table 2. Correlation between population and energy consumption.

| Growth rate of population in the current period | Pearson correlation | Significance (bilateral) | Growth rate of energy consumption in the current period |
|-----------------------------------------------|---------------------|--------------------------|-------------------------------------------------------|
|                                               |                     |                          | -0.926                                                |
|                                               |                     |                          | -0.419                                                |
| Growth rate of population in the last period   |                     |                          | -0.408                                                |
|                                               |                     |                          | 0.834                                                 |
|                                               |                     |                          | 0.039                                                 |

2.6. All Districts Energy Consumption Prediction Method

In the all districts energy consumption prediction method, six factors are selected to predict the energy consumption: population, GDP, energy consumption per unit GDP, per capita energy consumption, population growth rate, and the proportion of industrial output value. These factors are recorded as \( P_{it}, GDPR_{it}, EP_{it}, GDP_{it}, SSS_{it} \). The energy consumption of each district is expressed by \( E_{it} \). Where \( i = \{1, 2, 3 \ldots 11\} \), representing 11 districts of Guangzhou. \( t = \{2010, 2012 \ldots 2017\} \), representing the year. And in order to weaken the large fluctuation and reduce the heteroscedasticity between the data, the natural logarithm transformation is carried out for each variable, recorded as \( LN_{P_{it}}, LN_{GDPR_{it}}, LN_{EP_{it}}, LN_{GDPP_{it}}, LN_{SS_{it}}, LN_{E_{it}} \). Then the current period energy consumption and the each factor of last period are used for correlation analysis. The analysis results are shown in table 3.

According to the analysis results in table 3, the last period factor which is most significant related to the current period energy consumption of each district is selected as the explanatory variable, and the energy consumption of the current period is the explained variable. The single linear regression model is constructed as follows:

\[
E_{it} = \alpha_i + \beta_i H_{it-1} + \epsilon_{it} \tag{10}
\]

where, \( \alpha_i \) is the intercept term of linear regression, \( \beta_i \) is the correlation coefficient of independent variable. \( H_{it-1} \) is the variable with the strongest correlation with the energy consumption in each district, and \( \epsilon_{it} \) is the random error term. \( i = \{1, 2, 3 \ldots 11\} \), \( t = \{2011, 2012 \ldots 2017\} \).

Finally, the system of linear equations consisting of 11 unary linear equations is obtained. The energy consumption prediction equation of Guangzhou is summed by the energy consumption of each district:

\[
\hat{E}_t = \sum_{i=1}^{11} \hat{E}_{i,t} = \sum_{i=1}^{11} \alpha_i + \sum_{i=1}^{11} \beta_i H_{i,t-1} \tag{11}
\]

where \( \hat{E}_t \) is the fitting value of energy consumption of Guangzhou in year \( t \), and \( \hat{E}_{i,t} \) is the energy consumption fitting value of each district. \( i = \{1, 2, 3 \ldots 11\} \), \( t = \{2011, 2012 \ldots 2018\} \). The prediction results \( \hat{E}_{2018} \) is the energy consumption of Guangzhou in 2018.

2.7. Data Sources and Future Data Requirements

In this paper, the prediction of energy consumption in Guangzhou takes 2010-2017 as the study time period, using the time series data of seven factors in total. The time series data of all 11 districts in Guangzhou are used in the all districts energy consumption prediction method. Population (city), energy consumption, regional GDP, population (district) and electricity consumption used in this paper are taken from Guangzhou statistical yearbook. The energy consumption of Guangdong province is taken from the statistical yearbook of Guangdong province. The information of industrial structure, energy consumption and regional GDP of 11 districts in Guangzhou comes from the social statistics bulletin of each district in 2010-2017.
Table 3. Pearson correlation table of the current period energy consumption and the each factor of last period in each district.

| District | Population | GDP | Per capita energy consumption | Per capita GDP | Energy consumption per unit GDP | The proportion of industrial output value |
|----------|------------|-----|--------------------------------|----------------|--------------------------------|------------------------------------------|
| Liwan    | 0.740      | 0.972 | 0.978                          | 0.959          | -0.946                        | -0.886                                   |
|          | 0.057      | 0.000 | 0.000                          | 0.001          | 0.001                         | 0.008                                    |
| Yuexiu   | 0.274      | 0.977 | 0.973                          | 0.972          | -0.968                        | -0.942                                   |
|          | 0.552      | 0.000 | 0.000                          | 0.000          | 0.000                         | 0.001                                    |
| Haizhu   | 0.907      | 0.981 | 0.969                          | 0.983          | -0.975                        | -0.941                                   |
|          | 0.005      | 0.000 | 0.000                          | 0.000          | 0.000                         | 0.002                                    |
| Tianhe   | 0.344      | 0.655 | 0.871                          | 0.710          | -0.638                        | -0.331                                   |
|          | 0.450      | 0.110 | 0.011                          | 0.074          | 0.123                         | 0.468                                    |
| Baiyun   | 0.942      | 0.942 | 0.444                          | 0.910          | -0.936                        | -0.944                                   |
|          | 0.001      | 0.002 | 0.319                          | 0.004          | 0.002                         | 0.001                                    |
| Huangpu  | 0.968      | 0.836 | -0.771                         | 0.356          | -0.803                        | -0.952                                   |
|          | 0.000      | 0.019 | 0.042                          | 0.433          | 0.030                         | 0.001                                    |
| Panyu    | 0.924      | 0.990 | 0.439                          | 0.938          | -0.981                        | 0.001                                    |
|          | 0.025      | 0.001 | 0.459                          | 0.018          | 0.003                         | 0.999                                    |
| Huadu    | 0.886      | 0.973 | 0.900                          | 0.963          | -0.970                        | -0.986                                   |
|          | 0.008      | 0.000 | 0.006                          | 0.001          | 0.000                         | 0.000                                    |
| Nansha   | 0.972      | 0.988 | 0.958                          | 0.969          | -0.963                        | -0.882                                   |
|          | 0.006      | 0.002 | 0.010                          | 0.006          | 0.008                         | 0.048                                    |
| Conghua  | 0.949      | 0.984 | 0.991                          | 0.984          | -0.972                        | -0.715                                   |
|          | 0.001      | 0.000 | 0.000                          | 0.000          | 0.000                         | 0.071                                    |
| Zengcheng| 0.681      | 0.880 | 0.660                          | 0.874          | -0.890                        | -0.940                                   |
|          | 0.136      | 0.021 | 0.154                          | 0.023          | 0.018                         | 0.005                                    |

The methods in this paper are applicable to the short-term prediction of short period and small sample, and they are practical and reproducible. The following annual data in table 4 are needed to apply each method in practice. At present, the data of each method mainly comes from the statistical yearbook with large amount of data. But the statistical yearbook of that year will be published at the end of the next year, while the annual prediction needs more real-time data to be useful. Among them, the annual city level data and provincial data have stable and real-time access, and the relevant model can get the prediction results of the next year through the annual data update. On the other hand, it is difficult to obtain synchronous and complete data of each district because of the different statistical standards and publication standards. The difficulty in obtaining district level data is a major problem faced by the short-term prediction. And the corresponding solutions will be discussed in the following.

### 3. Results

#### 3.1. Prediction Results

Table 5 shows the fitting results of energy consumption in Guangzhou, and the fitting results of 2018 represent energy consumption predicted value. Table 6 shows the deviation between the fitted value and the actual value of each model and the annual average deviation value.
**Table 4.** Data requirements for each model.

| Method                                                      | Population (city) | Electricity consumption | Energy consumption (city) | Energy consumption (province) | Energy consumption (district) | Related factors (district) |
|-------------------------------------------------------------|-------------------|-------------------------|---------------------------|------------------------------|------------------------------|---------------------------|
| Guangdong province energy consumption back-stepping method |                   |                         |                           |                              |                              |                           |
| Per capita electricity consumption prediction method        |                   |                         | ●                         | ●                            | ●                            |                           |
| Prediction method of relationship between energy consumption and population |                   |                         | ●                         |                              |                              |                           |
| Grey model (city)                                           |                   |                         |                           |                              |                              |                           |
| Grey model (district)                                       |                   |                         |                           |                              |                              |                           |
| All districts energy consumption prediction method           |                   |                         |                           |                              |                              | ●                         |

**Table 5.** Energy consumption fitting results of each model (Unit: 10ktce).

| Method                                                      | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  |
|-------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Prediction method of relationship between energy consumption and population | 4966  | 5157  | 5315  | 5490  | 5662  | 5879  | 6056  | 6162  |       |
| Per capita electricity consumption prediction method         | 4772  | 5059  | 5219  | 5320  | 5417  | 5604  | 5829  | 6007  | 6153  |
| All districts energy consumption prediction method           | 4942  | 5136  | 5339  | 5487  | 5648  | 5805  | 5967  | 6149  |       |
| Guangdong province energy consumption back-stepping method  | 4743  | 4934  | 5125  | 5316  | 5506  | 5697  | 5888  | 6079  | 6270  |
| Grey model (city)                                            | 4776  | 5033  | 5180  | 5332  | 5488  | 5648  | 5814  | 5984  | 6159  |
| Grey model (district)                                        | 4776  | 5039  | 5181  | 5329  | 5483  | 5643  | 5810  | 5985  | 6166  |
| Combination model                                            | 4997  | 5167  | 5325  | 5479  | 5650  | 5837  | 6012  | 6176  |       |
| Actual value                                                 | 4775  | 5013  | 5163  | 5333  | 5496  | 5688  | 5852  | 5961  |       |

3.1.1. The City Level Prediction Methods. The Guangdong province energy consumption back-stepping method is a single linear regression, the energy consumption ratio of Guangzhou to Guangdong province is average value, so the result doesn’t have fluctuation in equal increment prediction. However, the prediction results of per capita electricity consumption prediction method are fluctuated because the fluctuation of per capita electricity consumption and the ratio of electricity consumption to energy consumption. And the fluctuation of relationship between energy consumption and population prediction results is affected by population. These prediction results of the energy consumption of Guangzhou in 2018 by the three prediction methods are 6270, 6153 and 6162·10ktce respectively. In 2018, the actual energy consumption is 6129·10ktce, and the prediction deviation of each method is 2.301%, 0.392% and 0.538% respectively, while the average fitting deviation of each method is 0.782%, 0.802% and 0.577%. It indicates that the correlation between fitting accuracy and prediction accuracy is not obvious.
Table 6. Deviation of each model fitting results (%).

| Method                                         | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | Average deviation |
|------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------------------|
| Prediction method of relationship between energy consumption and population | 0.949 | 0.115 | 0.350 | 0.118 | 0.469 | 0.458 | 1.583 | 0.577 |
| Per capita electricity consumption prediction method | 0.072 | 0.897 | 1.058 | 0.256 | 1.473 | 1.508 | 0.403 | 0.747 | 0.802 |
| All districts energy consumption prediction method | 1.429 | 0.524 | 0.103 | 0.170 | 0.727 | 0.820 | 2.029 | 0.829 |
| Guangdong province energy consumption back-stepping method | 0.683 | 1.587 | 0.751 | 0.338 | 0.181 | 0.147 | 0.607 | 1.962 | 0.782 |
| Grey model (city) | 0.000 | 0.385 | 0.321 | 0.035 | 0.158 | 0.712 | 0.644 | 0.376 | 0.347 |
| Grey model (district) | 0.000 | 0.517 | 0.349 | 0.080 | 0.241 | 0.799 | 0.720 | 0.378 | 0.409 |
| Combination model | 0.329 | 0.066 | 0.156 | 0.319 | 0.683 | 0.268 | 0.838 | 0.379 |

3.1.2. Grey Model. The grey prediction model (district level, city level) has passed the residual test and grade ratio deviation test. From table 7, it shows that the deviation value generated by using the grey prediction method to fit the energy consumption of each district is large, because the energy consumption of each district is small and unstable compared with the city’s energy consumption. Lastly, there is little difference between the sum of each district fitting results and the fitting results of Guangzhou, indicating the accuracy cannot be improved only by expanding the data amount of energy consumption.

Table 7. Fitting results of grey model (Unit: 10ktce).

| District | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | Average deviation (%) |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------------------------|
| Liwan    | 258   | 260   | 266   | 271   | 277   | 283   | 288   | 294   | 301   | 1.360                   |
| Yuxiu    | 538   | 558   | 570   | 583   | 597   | 610   | 624   | 638   | 653   | 0.397                   |
| Haizhu   | 303   | 329   | 342   | 356   | 370   | 384   | 400   | 415   | 432   | 1.992                   |
| Tianhe   | 579   | 649   | 658   | 667   | 677   | 686   | 696   | 706   | 716   | 4.464                   |
| Baiyun   | 629   | 658   | 675   | 693   | 712   | 731   | 750   | 770   | 791   | 1.439                   |
| Huangpu  | 1,038 | 1,052 | 1,082 | 1,113 | 1,146 | 1,179 | 1,213 | 1,248 | 1,284 | 2.132                   |
| Panyu    | 465   | 450   | 459   | 468   | 478   | 487   | 497   | 507   | 518   | 3.004                   |
| Huadu    | 303   | 316   | 328   | 340   | 352   | 365   | 379   | 392   | 407   | 1.290                   |
| Nansha   | 284   | 343   | 373   | 405   | 440   | 478   | 519   | 564   | 612   | 3.919                   |
| Conghua  | 82    | 91    | 95    | 99    | 103   | 107   | 111   | 116   | 121   | 2.224                   |
| Zengcheng | 298  | 334   | 334   | 334   | 334   | 334   | 334   | 334   | 333   | 4.500                   |
| The sum of each district | 4,776 | 5,039 | 5,181 | 5,330 | 5,483 | 5,643 | 5,811 | 5,985 | 6,166 | 0.409                   |
| Guangzhou (city) | 4,776 | 5,033 | 5,180 | 5,332 | 5,488 | 5,648 | 5,814 | 5,984 | 6,159 | 0.347                   |

3.1.3. All Districts Energy Consumption Prediction Method. There are some differences in the main factors affecting energy consumption among districts; only one district has a strong relationship between energy consumption and population, which indicates that the population has an indirect
impact on energy consumption through affecting per capita GDP and per capita energy consumption, while the direct impact on energy consumption is weak. The average fitting deviation of this method is 0.829% (table 6). After summing the fitting results of each district, the deviation of the fitting result of Guangzhou is decreased. This is because the deviation of different time in each district is different, and the final overall deviation decreases because the deviation of each district offsets each other in summation. It means that if the fitting accuracy of each district can be improved, the fitting accuracy at the city level will be further improved. Table 8 shows the statistical description of the linear regression results of each district. It can be seen that each regression has passed the significance test. And figure 3 shows the main influencing factors of each district.

**Table 8. Statistical description of linear regression in districts.**

| District | Independent variable | F test value | Sig (F) | Adjusted $R^2$ | Coefficient $\beta$ | Constant term $\alpha$ | Average deviation (%) | Maximum deviation (%) |
|----------|---------------------|-------------|---------|----------------|---------------------|-----------------------|----------------------|----------------------|
| Liwan    | LNEP                | 107.71      | 0.00    | 0.94           | 1.38                | 4.09                  | 0.88                 | 1.99                 |
| Yuexiu   | LNGDP               | 103.49      | 0.00    | 0.94           | 0.24                | 4.47                  | 0.84                 | 1.63                 |
| Haizhu   | LNGDPP              | 144.96      | 0.00    | 0.96           | 0.37                | 5.18                  | 1.33                 | 3.06                 |
| Tianhe   | LNEP                | 15.65       | 0.01    | 0.70           | 1.14                | 4.81                  | 2.50                 | 7.99                 |
| Baiyun   | LNSS                | 40.79       | 0.00    | 0.86           | -0.53               | 5.70                  | 1.14                 | 2.92                 |
| Huangpu  | LNP                 | 75.58       | 0.00    | 0.92           | 0.54                | 4.59                  | 1.00                 | 1.98                 |
| Panyu    | LNGDP               | 153.93      | 0.00    | 0.97           | 0.37                | 3.47                  | 0.41                 | 1.25                 |
| Huadu    | LNSS                | 180.68      | 0.00    | 0.96           | -1.23               | 5.18                  | 0.94                 | 2.86                 |
| Nansha   | LNGDP               | 120.51      | 0.00    | 0.96           | 0.71                | 1.25                  | 1.13                 | 2.54                 |
| Conghua  | LNEP                | 260.80      | 0.00    | 0.97           | 1.04                | 4.14                  | 0.88                 | 2.97                 |
| Zengcheng | LNSS              | 30.18       | 0.01    | 0.85           | -0.86               | 5.26                  | 2.11                 | 6.00                 |

**Figure 3.** Main energy consumption influencing factors of each district in Guangzhou.
3.1.4. Combination Prediction. In 2018, the actual energy consumption of Guangzhou was 6129·10ktce. As the growth rate of energy consumption in 2017 was the lowest in Guangzhou in recent 8 years, 2016-2018 was a period of great fluctuation in energy consumption growth, so the prediction accuracy of the model was required to be higher.

The all districts energy consumption prediction method has a prediction result of 6149·10ktce in 2018, which is the closest to the actual value in all methods. Among other methods, the grey model with the highest fitting accuracy has a prediction value of 6159·10ktce. It indicated that although the method has a good fitting effect on the historical data trend, the prediction deviation is large due to the lack of factors which can affect energy consumption in the model. The prediction at the city level is suitable for a more stable growth of energy consumption case because their data amount is small and cannot add more factors to the methods. But the prediction accuracy does not change significantly if the data is only extended to the district level without considering more influencing factors. Therefore, one of the main functions of the refined prediction level is to add more influence factors into the prediction method. From the above analysis, it can be seen that under the 8-year data amount case, the all districts energy consumption prediction method has a larger data amount and can select different influencing factors according to the specific situation of each district, so its prediction accuracy is the highest.

In view of the factor shortage problem of most method, this paper attempts to use the average deviation as the weight to combine the fitting results of various methods.

Calculate the average deviation of six models, and assign the weight according to the following equation:

$$w_i = \frac{e_i - e}{e} \times \frac{1}{m-1} \tag{12}$$

where $e = \sum e_i$, $e_i$ is the mean deviation of each method, $i = 1,2,3,4,5,6$. $m$ is the number of methods; $w_i$ is the weight of each method.

The results in table 9 show that the average deviation of the combination model is 0.379%; the fitting accuracy is improved compared with most models. However, the predicted result in 2018 is 6176·10ktce, which is quite different from the actual value. It shows that although the combination model can integrate the prediction results of various methods, it does not necessarily improve the prediction accuracy.

| Contribution value of each method | Weight (No unit) | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|-----------------------------------|-----------------|------|------|------|------|------|------|------|------|
| Guangdong province energy consumption back-stepping method | 0.169 | 840 | 873 | 899 | 929 | 958 | 995 | 1025 | 1043 |
| Per capita electricity consumption prediction method | 0.157 | 795 | 820 | 836 | 851 | 881 | 916 | 944 | 967 |
| Prediction method of relationship between energy consumption and population | 0.156 | 770 | 800 | 831 | 855 | 880 | 904 | 929 | 958 |
| Grey model (city) | 0.158 | 781 | 811 | 841 | 871 | 902 | 932 | 962 | 992 |
| Grey model (district) | 0.181 | 913 | 940 | 968 | 996 | 1025 | 1055 | 1086 | 1118 |
| All districts energy consumption prediction method | 0.178 | 898 | 923 | 949 | 977 | 1005 | 1035 | 1066 | 1099 |
| Combination results (Summation) | | 4997 | 5167 | 5325 | 5479 | 5650 | 5837 | 6012 | 6176 |
| Combination results deviation (%) | | 0.32 | 0.06 | 0.15 | 0.31 | 0.68 | 0.26 | 0.83 |
3.2. Further Application of Prediction Method

The prediction results in the previous are mainly used to compare with the actual values and evaluate the prediction effect of each method. And in order to reflect the practicability of each method, the prediction results of each method in 2019 and 2020 are obtained by using the latest data available in 2018. But the all districts energy consumption prediction method cannot predict the energy consumption of each district after 2018 due to the data of each district is not released at the same time and it is difficult to collect it completely. However, the all districts energy consumption prediction method still has high reference value, which can be used as the main prediction method after the data collection channels are increased.

Table 10 shows the energy consumption prediction results of 2019 and 2020. The development trend characteristics of energy consumption in Guangzhou can be seen from the difference of prediction results of various methods. The high prediction result of the Guangdong province energy consumption back-stepping method indicates that the growth rate of energy consumption in Guangzhou will be lower than that of the Guangdong province. At the same time, the GDP growth rate of Guangzhou is also slightly lower than that of the Guangdong province, which shows that the economic development and energy consumption of Guangzhou are closely related, and the adjustment of industrial structure has not yet decoupled the economic development and energy consumption. On the other hand, the prediction result of per capita electricity consumption prediction method is lower than that of the prediction method of relationship between energy consumption and population, indicating that the electrification level in Guangzhou is gradually increasing. The grey model is mainly based on the trend of energy consumption in the past, so its high predicted result indicates that the growth rate of energy consumption in Guangzhou is in a declining stage. In the future, with the increasing constraint of energy consumption control, the growth rate of energy consumption is expected to decline to the constraint target. However, all prediction results show that the energy consumption of Guangzhou will exceed the 2020 control target of 6282·10ktce issued by Guangdong province to Guangzhou in 2019, so it is unlikely to complete the control goal during the 13th Five Year Plan period. Guangzhou government should further strengthen energy management measures and complete the energy consumption control task during the 14th Five Year Plan period.

Table 10. Comparison of extrapolated predicted values of Various Models (Unit: 10ktce).

| Predicted value                                      | 2019 | 2020 |
|------------------------------------------------------|------|------|
| Prediction method of relationship between energy consumption and population | 6364 | 6571 |
| Per capita electricity consumption prediction method | 6293 | 6426 |
| Guangdong province energy consumption back-stepping method | 6461 | 6651 |
| Grey model (city)                                    | 6339 | 6525 |
| Grey model (district)                                | 6356 | 6554 |

4. Conclusion and Discussion

4.1. Conclusion

In this paper, from aspects of model factors and data levels, a variety of prediction methods of energy consumption suitable for short cycle data are established. According to the prediction result, here comes to some conclusions:

(1) In the aspect of prediction method, only expanding the data from city level to district level without introducing new factors cannot significantly improve the fitting accuracy and prediction accuracy. Although the combination prediction model at the city level improves the fitting accuracy, it is still unable to effectively predict the short-term fluctuations. While the all districts energy consumption prediction method carries out prediction according to the energy consumption characteristics of each district, and finally the prediction effect of energy consumption in Guangzhou is significantly improved. So the short-term fluctuation can be predicted better by the way of refining
the data level and putting multiple factors in the method.

(2) In the aspect of practical application, in addition to the prediction accuracy, each prediction result has other uses. The prediction results of the Guangdong province energy consumption back-stepping method are closer to the average trend in a short period, which can be used as a reference value to judge the fluctuation range of energy consumption. When it combination with the high prediction accuracy method, the abnormal trend of energy consumption can be forewarned in advance. Furthermore, due to the short refresh cycle (monthly) of population and electric power data, the per capita electricity consumption prediction method can be used with the annual energy consumption data for monthly prediction, and the energy consumption can be controlled in time to achieve the control target of the whole year. Lastly, there are many variables involved in the all districts energy consumption prediction method, so its prediction result can be traced back to the specific variables of each district when the prediction are abnormal, which plays an auxiliary decision-making role in the energy consumption control at the district level.

(3) In the aspect of method promotion, if government wants to apply Guangzhou energy consumption prediction method to GBA, they need to unify the statistical caliber, frequency and method of energy consumption of each city in GBA. At present, the energy consumption data of Guangzhou has many problems, such as the difficulty of obtaining district level data, the lack of real-time statistical data, etc., which makes Guangzhou energy management only have the annual plan of the city level, and it is difficult to assign the energy consumption management objectives and responsibilities to specific districts. And the monthly data will greatly enrich the data amount of energy consumption, which is conducive to establish a more accurate prediction model for monthly prediction. Therefore, when the prediction method is applied to GBA, it can also achieve more accurate energy consumption prediction and refined energy management by means of refine energy data statistics to district level, establishing monthly reporting mechanism, strengthening the information interconnection of government departments, etc. Table 11 shows the data demand for the promotion of the method to GBA. Among them, the city level data is the most basic demand for the promotion of the prediction method in this paper, and the district data is the further demand for improving the prediction accuracy of each method.

Table 11. Prediction data demand of the Guangdong-Hong Kong-Macao Greater Bay Area.

| Level | Energy consumption | GDP | Population | Industrial structure |
|-------|-------------------|-----|------------|---------------------|
|       | Annual (A)        | Quarterly (Q) | Monthly (M) | A | Q | M | A | Q | M |
| City  | ●                 | ●              | ●          |     |     |   |     |     |     |
| District | ●              | ●              | ●          |     |     |   |     |     |     |

4.2. Discussion
In this paper, the influence factors of each prediction method are still few, and the long-term relationship between each influence factor and energy consumption cannot be determined due to the small amount of data. For a better research, researcher can predict the energy consumption of each industry and analyze the energy consumption main influencing factors of each industry from the industry angle. In addition, researchers can also predict and analyze the energy consumption of main energy consumption enterprises. According to the energy consumption characteristics of each enterprise, the main energy consumption enterprises can be divided into several types. And then analysis the energy consumption law of each type of main energy consumption enterprise. Using enterprise data to predict energy consumption of Guangzhou can increase the amount of data, making the prediction accuracy greatly improved.

On the other hand, there are some difficulties in obtaining long-term stable data, which mainly due to the lack of a complete and unified energy data reporting mechanism in each district. So the district energy competent department shall strengthen the assistance to the city’s energy competent department, establish the district-city information exchange channel, and timely report the energy related data of
each district. And the city’s competent energy department should formulate a district level energy information collection system, prepare report table on the basic situation of energy for information collection and urge each district to submit it on time.

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