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Prediction model of energy consumption in Jiangsu Province based on constraint condition of carbon emission

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Abstract. In order to achieve the targets for energy conservation and economic development goals in Jiangsu Province under the constraint of carbon emission, this paper uses the gray GM (1,1) model to predict and optimize the consumption structure of major energy sources (coal, oil, natural gas, etc.) in Jiangsu province in the "13th Five-Year" period and the next seven years. The predictions meet the requirement of reducing carbon dioxide emissions per unit GDP of China by 50%. The results show that the proposed approach and model is effective. Finally, we put forward opinions and suggestions on the way of energy-saving and emission-reduction, the adjustment of energy structure and the policy of coal consumption in Jiangsu Province.

1. Carbon emission constraint

Since the industrial revolution, the international economy has changed enormously. However, the rapid growth of the global economy is based on the high input, high consumption and low efficiency of the extensive production. A large number of carbon emissions have become the chief culprit of global warming. In order to curb global warming, China has actively cooperated with other governments to promote low-carbon economy with the core of reducing carbon emissions [1].

Jiangsu is a province with large energy consumption. The rapid development of the economy also causes great pressure to the environmental quality, which causes that the major pollutant emissions in Jiangsu economic output have exceeded the national average. The energy bottleneck, environmental carrying capacity and other environmental resources constraints faced by Jiangsu province are increasing day by day [2]. Reasonable control of carbon dioxide and other greenhouse gas emissions, scientific and accurate prediction of coal consumption in the future, can play the key roles in the formulation of relevant development plans and policies by the state and regional government related functional departments [3]. Accurate grasp of the trend of coal consumption, accurate prediction of the future demand of coal can guide the production and supply of coal in a timely manner. It is of great significance to ensure the safety of coal supply in China [4].

The calculation of CO₂ emissions usually adopts the carbon emission coefficient method, which refers to the amount of carbon emissions per unit energy produced during the process of burning or using for each kind of energy [5]. The relationship of carbon emissions between energy consumption and carbon emission coefficient is showed as follows:



$$A_{n,i} = \frac{T_{n,i} \cdot \beta_i \cdot \varphi}{\alpha_i}$$

Where, $i=1, 2, 3$, respectively represent raw coal, oil and gas. $A_{n,i}$ is carbon emission and $T_{n,i}$ is energy consumption for raw coal, oil and gas. $\alpha_i = [0.7143, 1.4286, 1.3300]$ is the coefficient of equivalent coal for energy determined by the amount of carbon in the chemical formula. $\beta_i = [0.7476, 0.5825, 0.4435]$ is energy carbon emission coefficient set by the national development and reform commission. φ is the conversion factor of carbon emissions to CO₂ emissions, $\varphi = 44/12 = 3.67$.

Therefore, the total carbon emissions over the years are:

$$A_n = \sum_{i=1}^3 A_{n,i}$$

The carbon emission restriction is mainly embodied in the reduction rate of carbon dioxide emissions per unit area, that is to say, the decrease in carbon dioxide emissions per unit area of GDP compared with the previous year's emissions, abbreviated as carbon dioxide emission reduction rate per unit GDP. Relationships are as follows:

$$\eta_{n+t} = \frac{\frac{A_{n+t}}{GDP_{n+t}} - \frac{A_n}{GDP_n}}{\frac{A_n}{GDP_n}} \quad (1)$$

Use ρ_n to indicate the carbon dioxide emission rate per unit GDP in the upper model, the formula (1) can be expressed as:

$$\eta_{n+t} = \frac{\rho_{n+t} - \rho_n}{\rho_n} \quad (2)$$

According to the data from the National Bureau of statistics, the total energy carbon emissions of Jiangsu and the carbon dioxide emission per unit GDP since 1990 have been calculated, which are shown in table 1. As can be seen from table 1, China's total energy consumption, total carbon emissions and regional GDP values have shown a steady upward trend in recent years. However, due to the continuous change of the proportion of raw coal, oil and natural gas in total energy consumption, the ratio of rising between A_n and GDP_n is inconsistent, which eventually leads to a trend of decreasing annual carbon dioxide emission per unit GDP as shown in figure 1.

Table 1. Calculation for carbon dioxide emissions rate per unit of GDP.

year	Total energy consumption (tec)	$A_{n,1}$ --Carbon consumption of raw coal (10^4 t)	$A_{n,2}$ --Carbon consumption of oil (10^4 t)	$A_{n,3}$ --Carbon consumption of gas (10^4 t)	A_n --Total carbon emissions (10^4 t)	Regional GDP gross (Billion yuan)	Carbon dioxide emissions rate per unit of GDP (t/yuan $\times 10^{-4}$)
1990	4123.10	12278.57	1091.08	5.04	13374.68	651.82	20.52
1991	4382.20	13117.50	1179.30	5.36	14302.16	744.94	19.20
1992	4922.30	14696.41	1464.48	6.02	16166.90	922.33	17.53
1993	5508.10	16635.51	1663.46	6.74	18305.70	1208.85	15.14

1994	5586.50	17000.89	1687.12	6.83	18694.85	1321.85	14.14
1995	5509.00	16807.36	1762.55	6.74	18576.64	1416.50	13.11
1996	5780.80	17348.19	1858.16	7.07	19213.42	1601.38	12.00
1997	6296.50	19113.41	1958.04	7.70	21079.16	2136.02	9.87
1998	6625.80	20087.47	2000.99	8.11	22096.57	2998.16	7.37
1999	7357.70	22645.12	2024.02	3.25	24672.39	4057.39	6.08
2000	8047.20	24396.68	2153.55	3.09	26553.32	5155.25	5.15
2001	8111.20	24217.35	2231.32	2.27	26450.95	6004.21	4.41
2002	7991.10	23613.27	2365.52	1.96	25980.75	6680.34	3.89
2003	8118.00	23614.35	2403.09	2.76	26020.20	7199.95	3.61
2004	8163.50	24028.88	2526.42	3.58	26558.88	7697.82	3.45
2005	8612.40	24226.44	2935.73	3.90	27166.08	8553.69	3.18
2006	8881.40	24710.40	2814.98	3.41	27528.79	9456.84	2.91
2007	9608.60	26770.51	3002.37	11.75	29784.62	10606.85	2.81
2008	11060.70	29967.23	3654.52	13.52	33635.28	12442.87	2.70
2009	13651.70	36620.44	4000.36	50.08	40670.88	15003.60	2.71
2010	16895.40	46683.22	4824.57	227.24	51735.02	18598.69	2.78
2011	18742.20	51354.50	4931.63	504.15	56790.28	21742.05	2.61
2012	20604.40	55508.28	5236.80	730.59	61475.67	26018.48	2.36
2013	21775.50	56406.93	4948.45	1038.36	62393.74	30981.98	2.01
2014	23709.00	57575.79	5684.39	1031.48	64291.66	34457.30	1.87
2015	25774.00	63321.72	6404.41	1163.85	70889.97	41425.48	1.71

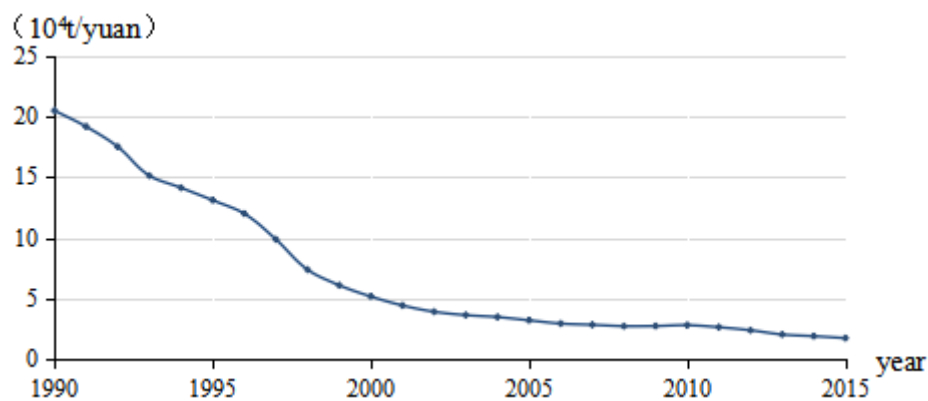


Figure 1. Change trend chart for carbon dioxide emissions rate per unit of GDP.

2. Establishment of grey GM (1,1) model of energy consumption structure

GM (1, 1) model is essentially a differential equation based on the original data sequence, which is the most representative in the gray modeling model [6]. It directly transforms the event sequence data into differential equations, and uses the system information to quantify the abstract model [7]. In the GM model, the original data sequence is accumulated at first, so that the accumulated data presents a certain rule, and then the typical curve is used to fit the graph. The specific steps are as follows:

- First test the data, and require the series ratio to meet the following conditions

$$\sigma(i) = \frac{x^{(0)}(i-1)}{x^{(0)}(i)} \in (e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}}) (i = 2, 3, \dots, n)$$

After inspection, if all series ratios belong to $(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}})$, then the GM (1, 1) model can be established.

- Assume there exists the time series data:

$$x^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)\}$$

Make a cumulative for sequence $x^{(0)}$ to generate sequence $x^{(1)}$, so that the item t of the new data sequence $x^{(1)}$ is the sum of the first t items of the original data sequence $x^{(0)}$, i.e.

$$x^{(1)} = \{x^{(1)}(1), x^{(1)}(2), \dots, x^{(1)}(n)\} = \left\{x^{(0)}(1), \sum_{t=1}^2 x^{(0)}(t), \dots, \sum_{t=1}^n x^{(0)}(t)\right\}$$

- the mean series $z^{(1)} = (z^{(1)}(2), z^{(1)}(3), \dots, z^{(1)}(n))$ can be obtained by averaging the cumulative sequence $x^{(1)}$

$$z^{(1)}(k) = \frac{\sum_{t=1}^k x^{(0)}(t)}{k}$$

If there is no difference in mean series, that is

$$z^{(1)}(k) = \alpha z^{(1)}(k) + (1 - \alpha)z^{(1)}(k - 1) \quad (k = 2, 3, \dots, n)$$

It indicates that the predicted sequence is less relevant to the original sequence. The further cumulative sequence is required

- The corresponding differential equations of GM (1, 1) model are established

$$\frac{dx^{(1)}}{dt} + \delta x^{(1)} = \mu$$

Where, δ represents development gray number and μ represents the endogenous control of gray number

- Parameter estimation for δ, μ (least square method)

$$\hat{\delta} = (B^T B)^{-1} B^T Y_n$$

- Establish the cumulative time series forecasting model.

$$\hat{x}^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{\mu}{\delta} \right] e^{-\delta k} + \frac{\mu}{\delta}, \quad k = 0, 1, 2, \dots, n$$

- Make the difference to get the original forecast

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) = \left(x^{(0)}(1) - \frac{\mu}{\delta} \right) \cdot (e^{-\delta k} + e^{-\delta(k-1)})$$

- After the reduction value is derived from the model, the accuracy of the gray model must be tested by residuals:

$$\xi(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{\hat{x}^{(0)}(k)} \quad (k = 1, 2, \dots, n)$$

If $\xi(k) < 0.2$, the general requirements are met. If $\xi(k) < 0.1$, the effect is better.

3. The solution of GDP prediction model

In this section, we establish the GM (1, 1) prediction model based on the discussion of the above constraints on carbon emissions. First of all, we forecast the growth of energy consumption and GDP in Jiangsu Province for the "13th Five-Year" and the next five years. Then according to the indicators of constraints by provisions of the state that in 2020, the carbon dioxide emissions per unit GDP of Jiangsu were reduced by 50%, the consumption structure of coal, oil, gas is optimized.

Firstly, taking the data of GDP samples in Jiangsu Province from 1990 to 2015 to predict by using GM (1, 1) model. Then, the model is analyzed and tested by the relative error and residual value between the real value and the predicted value. Finally, the GDP of Jiangsu Province in 2016 -2022 is predicted by the model.

Establish a set of primitive sequences based on GDP statistics:

$$x^{(0)} = (651.82, 744.94, \dots, 34457.30, 41425.48)$$

In this paper, by using MATLAB software, it is easy to obtain model parameters:

$$\delta = -0.1550, \mu = 796.0442$$

Thus, the GDP prediction model is:

$$y = -5137.23 + 5789.05 * \exp(0.154956 * t)$$

Through the model, the prediction of GDP in 1990 -2015 is calculated, and the relative error and residual error are analyzed which are shown in table 2.

Table 2. Relative error and residual index of real value and predicted value.

year	GDP	relative error	residual	year	GDP	relative error	residual	year	GDP	relative error	residual
1990	651	0	0	1999	4057	0.1739	4.29E-05	2008	12442	-0.0864	6.95E-06
1991	744	-0.3024	0.000406	2000	5155	0.2408	4.67E-05	2009	15003	-0.0520	3.47E-06
1992	922	-0.2283	0.000247	2001	6004	0.2389	3.98E-05	2010	18598	0.0090	4.87E-07
1993	1208	-0.0942	7.80E-05	2002	6680	0.2013	3.01E-05	2011	21742	0.0102	4.71E-07
1994	1321	-0.1684	0.000127	2003	7199	0.1347	1.87E-05	2012	26018	0.0342	1.32E-06
1995	1416	-0.2731	0.000193	2004	7697	0.0551	7.16E-06	2013	30981	0.0530	1.71E-06
1996	1601	-0.3148	0.000197	2005	8553	0.007	8.33E-07	2014	34457	0.005883	1.71E-07
1997	2136	-0.1509	7.07E-05	2006	9456	-0.0485	5.14E-06	2015	41425	0.0345	8.33E-07
1998	2998	0.0425	1.42E-05	2007	10606	-0.0915	8.63E-06				

The relative error diagrams are showed in figures 2 and 3 as follows:

As can be seen from the diagram, GM (1, 1) model prediction is very accurate, especially after fifteenth years of prediction, that is, the GDP data after 2005, the relative error between the predicted and the true values is basically between -0.1 and 0.1, and the overall mean error is 0.146. From years' relative error, the fluctuation of GDP is small, and it is basically in steady growth. It can be seen that GM (1, 1) model achieves good fitting effect and can predict GDP value very well.

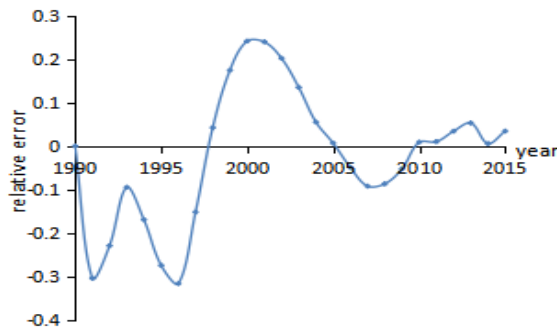


Figure 2. Relative error of prediction results.

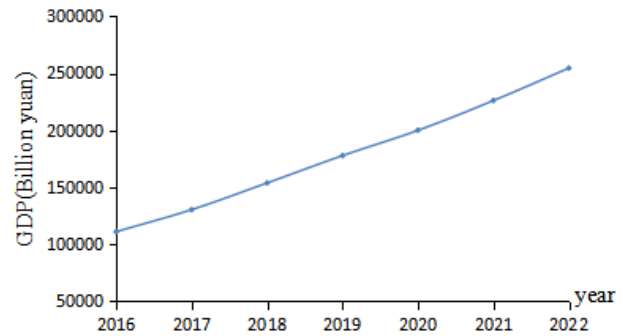


Figure 3. The GDP forecast value from 2016 to 2022.

Therefore, the GDP forecast value by GM (1, 1) model from 2016 to 2022 is in table 3 as follows:

Table 3. The GDP forecast value from 2016 to 2022.

year	2016	2017	2018	2019	2020	2021	2022
GDP (Billion yuan)	110876.98	130248.41	153654.78	177654.58	199857.56	225986.57	254471.38

4. Energy consumption prediction model

The method and process of the energy consumption forecasting model is basically similar to the third section in this paper, so it is omitted. Only prediction model and prediction results are given here:

$$\begin{cases} y_1 = -34418.3 + 37617.8 * \exp(0.713545e^{-1} * t) \\ y_2 = -10037.9 + 10767.7 * \exp(0.687776e^{-1} * t) \\ y_3 = -63.809700 + 67.92970 * \exp(0.326690 * t) \end{cases}$$

Using GM (1, 1) model, the prediction of energy consumption in Jiangsu province from 2016 to 2022 is shown in figure 4 and table 4 as follows:

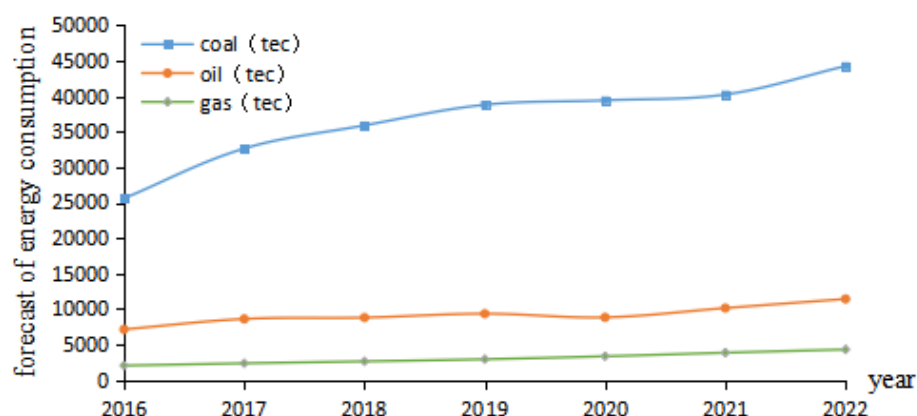


Figure 4. Forecast of energy consumption in Jiangsu from 2016 to 2022.

Table 4. Forecast of energy consumption in Jiangsu from 2016 to 2022.

year	Coal (tec)	Oil (tec)	Gas (tec)
2016	25588.23	7131.013	2028.254

2017	32619.51	8600.24	2347.357
2018	35883.53	8791.086	2618.979
2019	38785.96	9335.081	2917.801
2020	39413.88	8821.068	3333.539
2021	40230.61	10132.95	3836.462
2022	44245.53	11416.45	4293.969

5. Optimization of energy consumption structure

According to the above GDP forecast of Jiangsu during the period of 15th Five-Year and over the next seven years, it can be obtained that the GDP value in 2020 is 199857.56 Billion yuan. We can see from the formula (2) that the carbon emission restriction is the carbon dioxide emission rate per unit GDP not greater than 1.39 in 2020, which can predict the carbon dioxide emissions of that year:

$$\sum_{i=1}^3 A_{n,i} = \rho_n \cdot GDP_n$$

Also, total carbon emissions are made up of carbon emissions from coal, oil and natural gas. Therefore, the upper form can be translated into:

$$A_{n,1} + A_{n,2} + A_{n,3} \leq \rho_n \cdot GDP_n$$

Combining formula 1, An inequality of consumption of coal, oil and gas can be obtained:

$$3.7349T_{n,1} + 1.4951T_{n,2} + 1.2227T_{n,3} \leq \rho_n \cdot GDP_n$$

Taking the $T_{n,1}, T_{n,2}, T_{n,3}, \rho_n, GDP_n$ of 2020 into the above formula, we can get

$$164472.3 < 199857.56$$

So the consumption predictions of major energy sources in Jiangsu in the next seven years through the GM (1, 1) model meet the requirement of reducing carbon dioxide emissions per unit GDP of China by 50%. The results show that the proposed approach and model are effective.

6. Conclusion

From the prediction results of energy consumption, in the "13th Five-Year" period, the short-term energy consumption structure in Jiangsu province is still dominated by coal, the energy consumption accounts for between 71.7%-76.4%, and the average is 74.2%. Analysis of the data shows that in the next few years, the proportion of oil in the consumption structure is decreasing at a steady rate, while the proportion of demand for natural gas is increasing year by year, which indicates that China's energy structure is shifting towards clean energy and new energy sources. In short, as China's industrialization process, the reserves of non-renewable energy sources are not able to meet the growing demand for energy. Therefore, how to improve energy efficiency and find alternative energy sources will become a major problem facing China's energy industry in the future.

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