Forecast and Analysis of Regional Energy Demand Based on Grey Linear Regression Forecast Model

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Abstract. Energy is an important material basis for guaranteeing and promoting economic growth and social development. In order to predict the future energy demand for regional energy in Liaoning Province, this paper uses the gray forecast model to make reasonable predictions on regional energy in Liaoning. This paper first establishes a gray prediction model, analyzes the applicable environment and conditions of the gray prediction model, and secondly uses the gray prediction model to predict the energy of Liaoning Province from 2010 to 2019, and compares it with the actual data and elastic coefficient method. It shows that the prediction accuracy based on the gray prediction model is significantly higher than that of the traditional elasticity coefficient prediction method, which proves the scientifc and effectiveness of the model for regional energy demand prediction. Finally, on this basis, this paper uses the grey prediction model to analyze the energy of Liaoning Province from 2020 to 2029. The method and data can provide reliable data basis for the planning of Liaoning power grid and the evolution of the future power grid.

1. Introduction
Energy is not only an important material basis for human survival and reproduction, but also an important material basis for the development of national economy and the improvement of people's living standards. For Northeast China, the total population, the demand for energy from industrialization and urbanization, as well as the structural factors of energy, are generally not optimistic [1-2]. In order to provide scientific basis for energy planning and policy-making, it is of great practical significance to ensure the energy supply in Northeast China and maintain the healthy, stable and sustainable development of national economy [3-4].

At present, the development of energy demand forecasting model mainly goes through several stages. The first stage is before 1970s. Most of the energy demand forecasting and planning are based on the establishment of single objective function energy model. In the second stage [5-6], in the early 1970s, Dennis L. meadows et al. Established the so-called "doomsday model" to study the energy demand problem for the first time. Later, the two oil crises in the 1970s seemed to confirm the conclusions reached by meadows and others [7], which not only attracted the attention of economists, but also attracted the attention of engineering and technical experts. Since then, scholars at home and abroad have carried out a lot of research on energy forecasting. Based on the demand theory of
In economics, Prosser (1985) and others established energy demand function to forecast energy demand by analysing the factors influencing energy demand. In 1995, Noel D. URI et al. introduced the climate factor into the energy demand function to make it more realistic and economic. At present, with the development of energy network, the model of energy network is more and more complex, and the load change of demand side is more and more open. How to accurately forecast the regional energy demand is a hot and difficult problem in power system research at home and abroad.

In this paper, aiming at the regional energy of Liaoning Province, using the grey prediction model, the paper establishes an energy demand prediction model with good accuracy, which can reduce the loss of information to the maximum extent, improve the accuracy of prediction, and provide scientific decision-making reference for the formulation of regional energy planning.

2. Grey prediction model

The grey prediction method is an effective method to generate the original discrete data. It can offset and weaken the influence of random factors through the accumulation effect, find the system change rule from the generated number sequence, and establish its corresponding grey prediction model.

For the original data column at a given time:

\[ \{ x_i^0 (t) \}, i = 1,2 \cdots N; t = 1,2 \cdots M \]  

Generally, it cannot be directly emulated because the time data are mostly random and irregular. If the original data sequence the new data column can be obtained by accumulating the columns \( \{ x_i^0 (t) \} \), among \( x_i^0 (t) = \sum_{k=1}^{i} x_k^0 (k) \), This generation has two purposes: one is to provide intermediate information for emulating; the other is to weaken the randomness of the original data sequence. As shown in fig 1(a), the curve of the original data sequence has obvious swing. As shown in fig 1(b), the graph is a curve generated by one-time accumulation. Obviously, the regularity of the original sequence is enhanced, and the randomness is weakened. It can be seen that the randomness of the data sequence generated by accumulation is obviously reduced. Generally speaking, for non-negative data series, the more times of accumulation, the more obvious the weakening of randomness and the stronger the regularity. In this way, it is easy to approximate with an exponential curve.

In the operation of the real economic system, energy consumption Ji is affected by known factors such as the speed of economic development, and also by unknown factors such as structural adjustment and transportation. Therefore, the energy consumption system is a dynamic grey system, and the grey GM (1,1) model can be established.

![Figure 1. Comparison of random data before and after accumulation.](image)

The modeling process of grey prediction model is as follows, with sequence \( x_i^0 \) there are \( n \) observations, \( x_i^0 (1), x_i^0 (2), x_i^0 (3), \cdots x_i^0 (n) \). To \( x_i^0 \) do cumulative generation, get new data \( x_i^0 \), its elements \( x_i^0 (k) \) are:

\[ x_i^0 (k) = \sum_{j=1}^{k} x_i^0 (j) \quad i = 1,2,\cdots n \]  

Among them are: \( x_i^0 (1) = x_i^0 (1) \)
For the sequence $x^{(1)}$, the albino equation of prediction model can be established:

$$dx^{(1)}/dt + ax^{(1)} = u$$  \hspace{1cm} (4)$$

Where $a$ and $u$ are undetermined parameters, their values can be obtained by least square method:

$$[a, \ u] = (B^T B)^{-1} B^T y_a$$ \hspace{1cm} (5)$$

$$B = [-0.5(x^{(1)}(n-1) + x^{(1)}(n))]_{n=0}^{(n-1)} \quad y_a = [x^{(0)}(n)]_{n=0}^{(n-1)}$$ \hspace{1cm} (6)$$

The GM (1,1) prediction model is obtained by substituting $a$ and $u$ into the albino equation and solving the differential equation:

$$x^{(1)}(k + 1) = (x^{(0)}(1) - \frac{u}{a})e^{-at} + \frac{u}{a}$$ \hspace{1cm} (7)$$

By deriving the above formula, the reduction model is obtained as follows:

$$x^{(0)}(k + 1) = -a(x^{(0)}(1) - \frac{u}{a})e^{-at}$$ \hspace{1cm} (8)$$

The absolute error is as follows:

$$q^{(0)}(t) = x^{(0)}(t) - \hat{x}^{(0)}(t)$$ \hspace{1cm} (9)$$

In the formula, $q^{(0)}(t)$ is the residual term, $x^{(0)}(t)$ is the actual original data at time $t$, $\hat{x}^{(0)}(t)$ is the predicted data at time $t$.

The average $x^{(0)}(t)$ value obtained is $\bar{x}$ as follows:

$$\bar{x} = \frac{1}{n} \sum_{i=0}^{n} x^{(0)}(t)$$ \hspace{1cm} (10)$$

The $x^{(0)}(t)$ variance is $S_x$ as follows:

$$S_x = \frac{1}{n-1} \sum_{i=0}^{n} (x^{(0)}(t) - \bar{x})^2$$ \hspace{1cm} (11)$$

The posterior difference ratio $C$ is calculated as follows:

$$C = S_x / S_x$$ \hspace{1cm} (12)$$

Calculate the small error frequency $P$ as follows:

$$P = \left\{ q^{(0)}(t) - \bar{q} < 0.6745S_x \right\}$$ \hspace{1cm} (13)$$

In general, for good prediction, the smaller the $C$ is, the better; generally, $C < 0.35$ is required, and the maximum value is not more than 0.65; at the same time, the larger the $P$, the better; generally, $P > 0.95$, not less than 0.7.

3. Grey linear regression prediction

The gray forecast model is used in the forecast of power energy demand to solve the problem of the lack of data related to power energy demand during the economic transition period and there is no obvious rule. Ignoring the linear transformation law in the accumulated data, this will cause a certain deviation in the energy demand forecasting model. In this regard, this article combines the linear regression analysis with the gray model, and adds a linear part in step 5 of the gray prediction model, that is, formula (7) is changed to:

$$x^{(1)}(k) = \xi_1 e^{-at} + \xi_2 k + \xi_3$$ \hspace{1cm} (14)$$

Where: $\xi_1$, $\xi_2$, $\xi_3$, and $\rho$ are the undetermined parameters of the gray linear regression equation. The calculation formulas for these parameters are given below:

$$u_a = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) = \xi_1 e^{-at} (e^\rho t - 1) + \xi_2$$ \hspace{1cm} (15)$$
Define: \( H_r(k) = u_{k+r} - u_k \), where \( k=0, 1, \ldots, n-2-r \). Available:
\[
H_r(k) = \xi e^{-\rho k} (e^{\rho} - 1)
\]
(16)
Where, \( r=1, 2, \ldots, n-3 \). From the formula (15), the fitting calculation formula of the parameters \( \rho \) is:
\[
\rho(k) = \ln \left( \frac{H_r(k+1)}{H_r(k)} \right)
\]
(17)
Calculate each fitting value of parameter \( \rho \) according to the \( H \) data sequence under different values of \( r \), and use the mean value as the final fitting value of parameter \( \rho \):
\[
\rho = \frac{\sum_{k=1}^{n-3} \sum_{k=1}^{n-3} \rho(k)}{0.5(n-2)(n-3)}
\]
(18)
After obtaining the fitted value of parameter \( \rho \), formula (14) can be written as the following matrix form:
\[
[x^0]_{n+1} = [e^{-\rho \cdot n-1}]_{n+1} [\xi]_{n+1}
\]
(19)
\[
\xi = (Q^T Q)^{-1} Q^T X^0
\]
(20)
Combined with the above formula, the value of the undetermined parameter \( \xi \) can be determined by formula (20). Based on this, the gray linear regression equation is established, and then the gray prediction model is accumulated and subtracted to obtain the fitted or predicted value of energy demand.

4. Regional energy demand forecast
In this paper, the grey model method is used to forecast the multi energy demand. Energy consumption of Liaoning Province from 2010 to 2019 is shown in Table 1:

| Annual fee  | 2010  | 2011  | 2012  | 2013  | 2014  |
|------------|-------|-------|-------|-------|-------|
| Multi energy consumption | 3051.31 | 3798.55 | 3576.15 | 3708.65 | 3897.72 |

| Annual fee  | 2015  | 2016  | 2017  | 2018  | 2019  |
|------------|-------|-------|-------|-------|-------|
| Multi energy consumption | 4389.67 | 5687.42 | 6980.51 | 9012.21 | 11006.18 |

Using the grey model, the data from 2010 to 2019 are taken as the original data:
\[
(x^0(t)) = \{x^0(2010), x^0(2011), \ldots, x^0(2018), x^0(2019)\}
\]
(21)
The number sequence of one-time accumulation is
\[
x^{(1)}(k) = \{3051.31, 6849.68, \ldots, 44084.19, 55090.37\} \quad k = 10
\]
(22)
(2) Build database matrix \( B \) and \( y_a \):
\[
B = \begin{bmatrix}
-0.5(3051.31 + 6849.86) & 1 \\
-0.5(6849.86 + 10426.01) & 1 \\
\vdots & \vdots \\
-0.5(44084.19 + 55090.37) & 1
\end{bmatrix}, \quad y_a = \begin{bmatrix}
3767.45 \\
3543.57 \\
\vdots \\
11386.14
\end{bmatrix}
\]
(23)
(3) Establish \([a, u]^T\), available:
\[
[a, u]^T = \begin{bmatrix}
-0.180705885 \\
1715.393542
\end{bmatrix}
\]
(24)
(4) Establish the discrete-time response function is as follows:

\[
x^{(0)}(k + 1) = 2312.6538728 e^{0.180705885k} + 0.180705885
\]

(25)

(5) The table of model test and reduction model test is shown in Table 2.

Table 2 Multi-energy consumption forecast model checklist.

| Serial number | Calculated value | Original value | Residual | \( \left| x^{(0)}(t) - \tilde{q}(t) \right| \) |
|---------------|-----------------|----------------|----------|----------------|
| 1             | 2809.12         | 3798.55        | 989.43   | 1289.34        |
| 2             | 3456.25         | 3576.15        | 119.9    | 522.86         |
| 3             | 3767.89         | 3708.65        | -59.24   | 125.82         |
| 4             | 3798.04         | 3897.72        | 99.68    | 275.53         |
| 5             | 4219.78         | 4389.67        | 169.89   | 596.97         |
| 6             | 5709.81         | 5687.42        | -22.39   | 856.38         |
| 7             | 6813.56         | 6980.51        | 166.59   | 618.51         |
| 8             | 9035.12         | 9012.21        | -22.91   | 38.73          |
| 9             | 10098.34        | 11006.18       | 907.86   | 448.11         |

It can be seen from the table above, \( \bar{q} = -260.979, \ \bar{S}_e = 1719.08/0.6745 \), In order to satisfy \( \left| x^{(0)}(t) - \tilde{q}(t) \right| < 0.6745\bar{S}_e \), \( P = 1 > 0.95 \). From the above calculation, \( p = 1, \ c = 0.246 \). Therefore, the established model has good prediction accuracy and can be used for prediction.

Figure 2. Fitting diagram of grey model precision.

The results of several prediction models are reflected in the coordinate diagram. It can be seen from Figure 2 that the fitting accuracy of the grey prediction model is obviously better than that of the traditional coefficient prediction model.

(6) Forecast multi energy demand

According to the prediction model, the total amount of multi energy demand in Liaoning Province from 2020 to 2029 is predicted, and the results are shown in Table 3.

Table 3 Total energy demand in Liaoning Province from 2020 to 2029.

| Particular year | 2020    | 2021    | 2022    | 2023     | 2024     |
|-----------------|---------|---------|---------|----------|----------|
| Total consumption | 13657.39| 15378.23| 17981.22| 19897.89 | 25983.61 |
|                  | 39      | 23      | 22      | 9        | 61       |

| Particular year | 2025    | 2026    | 2027    | 2028     | 2029     |
|-----------------|---------|---------|---------|----------|----------|
| Total consumption | 30145.30| 34769.39| 39598.25| 48967.30 | 58789.30 |
|                  | 22      | 12      | 53      | 2        | 34       |

According to the data in Table 3, we can have scientific prediction of Liaoning Province's multi energy demand from 2020 to 2029, which provides reliable data basis for the planning of Liaoning power grid and the evolution of future power grid.
5. Conclusion

In order to ensure the reliability of energy and provide power for economic development, this paper carries out the prediction of comprehensive energy source demand in Liaoning Province. This paper establishes the selection grey prediction model, and forecasts the data from 2011 to 2019 according to the energy consumption of Liaoning Province in 2010, and compares with the actual data \( \bar{q} = 260.979 \), \( S = 1719.08 \), \( 0.6745 \), in order to satisfy \( |q(t) - \bar{q}| < 0.6745S \), \( P > 0.95 \). It is proved that the model has good prediction accuracy. At the same time, compared with the traditional elastic coefficient model, it is proved that the fitting degree between the grey prediction model and the original data is obviously better than that of the elastic coefficient model. Finally, this paper uses the grey prediction model to analyze the energy of Liaoning Province from 2020 to 2029, and the data can provide reliable data basis for the planning of Liaoning power grid and the evolution of future power grid.

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