Energy consumption forecasting using improved non-homogeneous exponential grey model

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Abstract. The classical non-homogeneous exponential grey model is a valid tool for accurate prediction with small samples. But the classical non-homogeneous exponential grey model needs to be improved for higher accuracy. In this paper, a new discrete non-homogeneous exponential grey model is proposed, and the background value of the new model is given by Simpson numerical integration formula. Further, the electricity consumption is given to validate the accuracy of the new model and the result illustrates the new model provides accurate prediction. In the example, the mean absolute percentage error is 2.14%. Finally, the new model is used to forecast the consumption of energy for China in 2025 and the result is 1076.08 million tons of standard coal. It is of great significance to make scientific decisions and plans on energy development.

1. Introduction

Economic development will inevitably bring about sustained growth in energy demand. With the continuous improvement of residents’ quality of life, the total consumption of living energy is increasing. The status and role of residents’ living energy consumption are becoming more and more prominent, and the competition between industrial production energy and residents’ living energy is becoming more and more fierce. Therefore, forecasting domestic energy consumption is beneficial to explore and improve the management methods and energy policies of domestic energy consumption and promote economic and social development.

According to the literature, many scholars have done a lot of research on the prediction model of energy consumption, including echo state network [1], time series model [2], grey model [3] and harmonic regression method [4], etc. Among many forecasting methods, time series models based on the historical data related to energy consumption, the calculation principle is simple, but it cannot reflect its internal influence factors element. The regression analysis method establishes a regression model, which requires a large amount of data and has low prediction accuracy. The strong point of grey model is that it has high accuracy for small sample data. Besides, the grey model has high calculation accuracy that can effectively fit and predict nonlinear data.

Grey theory is a new project be put forward by Deng in 1982. It takes small sample uncertain systems with some known information as the research object. It mainly analyzes some known information and makes scientific predictions based on it. In 1982, Professor Deng put forward the traditional GM (1,1) model and presented the whitening differential equation, separated the differential equation and used the least square method to estimate parameters. The predicted value can be obtained by using the solution of the whitening differential equation.
In recent years, a large number of excellent grey prediction models are produced based on the GM (1,1) model, such as the non-homogeneous exponential grey models those are NGM (1,1, knob) and NGM (1, 1, k, c) [5]. The establishment of background value is based on the trapezoid integration formula. However, their models show inaccuracy in some applications. Recently, the studied of traditional GM (1,1) model used the Simpson numerical integration formula to develop a new background value, and got a new model named GM_{SD} model [6]. And some computation results indicate that the GM_{SD} model provides accurate predictions. In the study, the background value improves the accuracy of the grey model effectively. Many authors put forward various discrete grey models and show good results through examples.

The purpose of this paper is for reconstructing a new background value of NGM (1, 1, k, c) model by Simpson formula. In this paper, we first make the discretization of differential equations and use the Simpson formula to get the new background value. Further, the iterative relationship is established by the new background value, and the parameters are estimated. Then the solution of the whitening equation is obtained through the constant variation method, and the recovery value is calculated by inverse accumulation generation operation. The new model based on the Simpson formula is called the SNGM (1, 1, k, c) model. After the establishment of the model, the calculation results are compared with GM (1,1) model, GM_{SD} model, NGM (1, 1, k) model and traditional NGM (1, 1, k, c) model through an example to illustrate the accuracy of SNGM (1, 1, k, c) model. Finally, we use the SNGM (1, 1, k, c) model to predict energy consumption for China in 2025 and analyze the results.

The rest of this paper is structured as follows. In section 2, we review the classical NGM (1, 1, k, c) model and use the Simpson formula to develop SNGM (1, 1, k, c) model. Section 3 gives an application example, which show the performance of the SNGM (1, 1, k, c) model. Finally, in section 4, we use the SNGM (1, 1, k, c) model to predict the domestic energy consumption in China, and the result analysis is given.

2. Improved non-homogeneous grey mode based on Simpson formula

2.1. The classical non-homogeneous grey mode

First of all, we can review the definition of the classical non-homogeneous grey mode NGM (1, 1, k, c).

Suppose there is a non-negative column \( X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)) \), accumulate it once to get \( x^{(1)}(k) \), where \( x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i) \).

Definition 1. [5] The whitening differential equation of the continuous NGM (1, 1, k, c) model is

\[
\frac{dx^{(1)}(t)}{dt} + ax^{(0)}(t) = bt + c
\]  

(1)

where \( a \), \( b \) and \( c \) are grey system parameters.

From the approximation of \( \frac{dx^{(1)}(t)}{dt} \), we get

\[
\frac{dx^{(1)}(t)}{dt} = \lim_{\Delta t \to 0} \frac{x^{(1)}(t) - x^{(1)}(t - \Delta t)}{\Delta t} \approx x^{(1)}(t) - x^{(1)}(t - 1) = x^{(0)}(t)
\]  

(2)

Suppose the background value is

\[
z^{(1)}(t) = \frac{1}{2} (x^{(1)}(t) + x^{(1)}(t - 1))
\]  

(3)

By approximation, the differential equation (1) can become

\[
x^{(0)}(t) + az^{(1)}(t) = bt + c
\]  

(4)

Definition 2. [5] The equation is called a grey differential equation for NGM (1, 1, k, c) model, where \( a \), \( b \) and \( c \) are system parameters.

\[
x^{(0)}(k) + az^{(1)}(k) = bk + c
\]  

(5)
From the least-square method, the parameters of NGM \((1, 1, k, c)\) model can be calculated by

\[
[a, b, c]^T = (B^T B)^{-1} B^T Y
\]

where,

\[
B = \begin{bmatrix}
-z^{(1)}(2) & 2 & 1 \\
-z^{(1)}(3) & 3 & 1 \\
\vdots & \vdots & \vdots \\
-z^{(1)}(n) & n & 1 \\
\end{bmatrix},
Y = \begin{bmatrix}
x^{(0)}(2) \\
x^{(0)}(3) \\
\vdots \\
x^{(0)}(n) \\
\end{bmatrix}
\]

2.2. The improved non-homogeneous grey mode

This section derives the discrete SNGM \((1, 1, k, c)\) model with Eq.(1) and the Simpson formula. Calculating the integration of Eq. (1) in the interval \([k-1, k+1]\), it gives

\[
\int_{k-1}^{k+1} x^{(1)}(t) dt = b \int_{k-1}^{k+1} t dt + \int_{k-1}^{k+1} c dt, \quad k = 2, 3, ..., n-1
\]

That is

\[
x^{(1)}(k+1) - x^{(1)}(k-1) + a \int_{k-1}^{k+1} x^{(1)}(t) dt = 2bk + 2c, \quad k = 2, 3, ..., n-1
\]

Using the Simpson formula, it gives

\[
\left(\frac{4}{3}\right) \int_{k-1}^{k+1} x^{(1)}(t) dt = \frac{x^{(0)}(k-1) + 4x^{(1)}(k) + x^{(1)}(k+1)}{3}
\]

Thus, Eq. (9) turns to

\[
x^{(1)}(k+1) - x^{(1)}(k-1) + \frac{4x^{(1)}(k) + x^{(1)}(k+1)}{3} = 2bk + 2c, \quad k = 2, 3, ..., n-1
\]

Simplify Eq. (11), it gives

\[
(a + 3)x^{(1)}(k+1) + 4ax^{(1)}(k) + (a - 3)x^{(1)}(k-1) - 6bk - 6c = 0, \quad k = 2, 3, ..., n-1
\]

Thus, we have established the discrete SNGM \((1, 1, k, c)\) model.

2.3. Parameter calculation for the improved non-homogeneous grey mode

From the definition of NGM \((1, 1, k, c)\) model, we can get that

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

Using the Simpson formula, the background value of the SNGM \((1, 1, k, c)\) model can be defined as

\[
z^{(1)}(k) = \frac{x^{(0)}(k-1) + 4x^{(1)}(k) + x^{(1)}(k+1)}{3}
\]

So, from Eq. (11) it gives

\[
x^{(1)}(k+1) - x^{(1)}(k-1) + az^{(1)}(k) = 2bk + 2c, \quad k = 2, 3, ..., n-1
\]

That is

\[
x^{(0)}(k) + x^{(0)}(k+1) + az^{(1)}(k) = 2bk + 2c, \quad k = 2, 3, ..., n-1
\]

We let \(k = 2, 3, ..., n-1\) substitute into the above formula and utilizing the least-square method to get parameters \(a\), \(b\) and \(c\), that is

\[
[a, b, c]^T = (B^T B)^{-1} B^T Y
\]
We know the Simpson numerical integration formula has higher approximation accuracy than the trapezoid formula, so the SNGM (1, 1, \(k\), \(c\)) model can have better performance in data prediction and fitting than the classical NGM (1, 1, \(k\), \(c\)) model.

2.4. The time response equation and the restored values for the improved non-homogeneous grey mode

Theorem 1. The time response equation of NGM (1, 1, \(k\), \(c\)) model can be expressed by

\[
\hat{x}^{(1)}(k) = (x^{(1)}(1) - \frac{b}{a} + \frac{b}{a^2} - \frac{c}{a})e^{-a(k-1)} + \frac{b}{a}k - \frac{b}{a^2} + \frac{c}{a}, k = 1, 2, \ldots, n
\]  

(19)

and the values of \(\hat{x}^{(0)}(k)\) are

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

(20)

where, \(C(1-e^a)\), \(\frac{b}{a}\) and \(a\) are independent parameters from each other. Thus, SNGM (1, 1, \(k\), \(c\)) model is called a non-homogeneous exponential grey model, which is used for imitating and forecasting the non-homogeneous exponential data.

2.5. Performance evaluation for the grey models

| Symbolic expression                  | Abbreviation | Calculation formula |
|--------------------------------------|--------------|---------------------|
| Relative Error                       | RE           | \[\left|\hat{x}^{(0)}(k) - x^{(0)}(k)\right|, k = 2, 3, \ldots, n\] |
| Mean Relative Error                  | MRE          | \[\frac{1}{n-1} \sum_{k=2}^{n} \left|\hat{x}^{(0)}(k) - x^{(0)}(k)\right|\] |
| Absolute Percentage Error            | APE(%)       | \[\left|\frac{\hat{x}^{(0)}(k) - x^{(0)}(k)}{x^{(0)}(k)}\right| \times 100\%, k = 2, 3, \ldots, n\] |
| Mean Absolute Percentage Error       | MAPE(%)      | \[\frac{1}{n-1} \sum_{k=2}^{n} \left|\frac{\hat{x}^{(0)}(k) - x^{(0)}(k)}{x^{(0)}(k)}\right| \times 100\%\] |
| Root Mean Squared Error              | RMSE         | \[\sqrt{\frac{1}{n-1} \sum_{k=1}^{n} (\hat{x}^{(0)}(k) - x^{(0)}(k))^2}\] |
| Average value of raw data            | \(\bar{x}\)  | \[\frac{1}{n-1} \sum_{k=1}^{n} x^{(0)}(k)\] |
| Average value of forecast data       | \(\hat{\bar{x}}\) | \[\frac{1}{n-1} \sum_{k=1}^{n} \hat{x}^{(0)}(k)\] |
| Standard deviation of raw data       | \(S_1\)      | \[\sqrt{\frac{1}{n-1} \sum_{k=1}^{n} (x^{(0)}(k) - \bar{x})^2}\] |
| Standard deviation of forecast data  | \(S_2\)      | \[\sqrt{\frac{1}{n-1} \sum_{k=1}^{n} (\hat{x}^{(0)}(k) - \hat{\bar{x}})^2}\] |
| Mean Square Error Ratio              | MESR         | \[\frac{S_2}{S_1}\] |
After the establishment of the SNGM \((1, 1, k, c)\) model, some calculation indicators are used to evaluate the performance of the model. In this paper, five different guidelines will examine the performance of competing models, including RE (Relative Error), MRE (Mean Relative Error), APE (Absolute Percentage Error), MAPE (Mean Absolute Percentage Error), RMSE (Root Mean Squared Error) and MSER (Mean Square Error Ratio). The MRE, APE, MAPE, RMSE, and MSER are defined as shown in Table 1.

3. Forecasting China’s electricity consumption based on the grey models

In this section, an empirical study is carried out and compared with other grey prediction models, which are GM \((1,1)\), GMSD \((1,1)\), NGM \((1, 1, k)\), and NGM \((1, 1, k, c)\) model.

The data in this subsection comes from the work of Zeng [7], we program these 15 groups of data with MATLAB and carry out modeling calculation, and the results are shown in Table 2. By comparing the error between the calculated value and the real value of every model, we can find that compared with GM \((1,1)\), GMSD \((1,1)\), NGM \((1, 1, k)\), and NGM \((1, 1, k, c)\) model, the SNGM \((1, 1, k, c)\) model has the highest accuracy on the whole.

### Table 2. Actual values and the result of simulated values for China’s electricity consumption (Billion kilowatt hours) based on the five models.

| Year | Actual value | GM(1,1) | GM SD (1,1) | NGM(1,1,k) | NGM (1, 1, k, c) | SNGM (1, 1, k, c) |
|------|--------------|---------|-------------|------------|-----------------|------------------|
| 2001 | 1480.8       | 1480.8  | 1480.8      | 1480.8     | 1480.8          | 1480.8           |
| 2002 | 1654.0       | 2034.0  | 2032.1      | 802.82     | 1385.1          | 2065.3           |
| 2003 | 1910.5       | 2214.5  | 2217.0      | 1348.91    | 1726.5          | 2401.5           |
| 2004 | 2203.3       | 2414.9  | 2417.0      | 1588.29    | 2073.8          | 2645.3           |
| 2005 | 2500.2       | 2624.9  | 2638.8      | 2324.74    | 2598.1          | 3084.6           |
| 2006 | 2865.7       | 2857.8  | 2878.8      | 2760.04    | 3095.6          | 3439.5           |
| 2007 | 3281.5       | 3111.4  | 3140.8      | 3163.66    | 3518.1          | 3777.8           |
| 2008 | 3495.7       | 3387.4  | 3426.5      | 3537.89    | 3924.5          | 4206.4           |
| 2009 | 3714.6       | 3687.9  | 3738.3      | 3884.89    | 4270.5          | 4609.6           |
| 2010 | 4192.3       | 4015.2  | 4078.4      | 4206.62    | 4643.9          | 5008.2           |
| 2011 | 4692.8       | 4371.4  | 4449.4      | 4504.93    | 4963.4          | 5415.1           |
| 2012 | 4959.1       | 4759.2  | 4854.3      | 4781.52    | 5268.4          | 5721.5           |
| 2013 | 5322.3       | 5181.5  | 5295.9      | 5037.98    | 5599.4          | 6087.5           |
| 2014 | 5523.3       | 5641.2  | 5777.7      | 5275.77    | 6013.0          | 6616.4           |
| 2015 | 5550.0       | 6141.7  | 6303.4      | 5496.25    | 5762.2          | 6589.3           |

### Table 3. Measuring indicators for China’s electricity consumption (Billion kilowatt hours) based on the five models.

| Indicator | GM(1,1) | GM SD (1,1) | NGM(1,1,k) | NGM (1, 1, k, c) | SNGM (1, 1, k, c) |
|-----------|---------|-------------|------------|-----------------|------------------|
| MRE       | 205.60  | 198.69      | 238.40     | 178.73          | 85.09            |
| MAPE(%)   | 6.21    | 6.02        | 9.03       | 5.17            | 2.14             |
| RMSE      | 252.91  | 273.09      | 322.90     | 201.48          | 116.35           |
| MSER      | 0.1742  | 0.1784      | 0.1773     | 0.0839          | 0.0810           |

According to Table 2 and Figure 1, we can see that the fitting effect of GM \((1,1)\), GMSD \((1,1)\), NGM \((1, 1, k)\) and NGM \((1, 1, k, c)\) model at the initial data point is very poor. We observe from Table 2 that at the first data point, the absolute percentage error is 22.98% of the GM \((1,1)\) model, and the value of GMSD \((1,1)\), NGM \((1, 1, k)\), NGM \((1, 1, k, c)\) and SNGM \((1, 1, k, c)\) are 22.86%, 51.46%, 16.26%, 5.91% , respectively. A similar situation occurred at the second data point, this indicates that compared with other models, SNGM \((1, 1, k, c)\) model has higher precision and accuracy in initial data simulation. We can also know that there is a general downward trend of the APE values for each model, this shows the fitting effect is getting better with time. By comparing the value of APE, we can find that the SNGM \((1, 1, k, c)\) model has better performance ability than other models.

On the whole, as can be seen from Table 3, the MRE, MAPE, RMSE, and MSER of the SNGM \((1, 1, k, c)\) model is 85.09, 2.14%, 116.35, and 0.0810, respectively. Compared with other grey models,
those values all are the smallest. Among them, the MRE value is smaller than other models. This also illustrates the advantages of the SNGM (1, 1, \(k\), \(c\)) model.

This example indicates that the simulating performances of the SNGM (1, 1, \(k\), \(c\)) model, which proposed in this paper, are the best among the five grey forecasting models in this case.

![Figure 1](Image) The forecast of China’s electricity consumption (Billion kilowatt hours) based on the five models.

![Figure 2](Image) The APE (absolute percentage error) of give grey models for China’s electricity consumption.

From Table 3 and Figure 2, we can find that the NGM (1, 1, \(k\)) model is the worst compared with the other four models from 2002 to 2005. The APE value about the NGM (1, 1, \(k\)) model is 7.02% in 2005, it is higher than other grey models, but the approximation effect gradually improved after 2005. At the same time, it can be seen from Figure 2 that the fitting effect of the SNGM (1, 1, \(k\), \(c\)) model is the best.

From Table 3 and Figure 3, we can know that the MRE, MAPE, and RMSE for the NGM (1, 1, \(k\)) model are 238.40, 9.03%, and 322.90, those values are obviously higher than the other four grey models. At the same time, the MRE, MAPE, RMSE, and MSER for SNGM (1, 1, \(k\), \(c\)) model is the smallest compared with other grey models. This also shows that in this case the accuracy of the
SNGM \((1, 1, k, c)\) model is the best and the NGM \((1, 1, k)\) model is the worst. Therefore, the SNGM \((1, 1, k, c)\) model has high accuracy compared with other gray forecast models in this case.

![Figure 3](image_url)

Figure 3. The MRE, MAPE, RMSE and MSER of five models for China’s electricity consumption.

4. Analysis and forecast of consumption of domestic energy in China

Energy, an important material resource, is related to national economic lifeline and the national defense security, which plays an important role in modernization. With the rapid development of the national economy, the energy sector is facing many challenges, and its total consumption and production structure have changed accordingly. Scientifically analyzing the situation of China’s domestic energy consumption and grasping the trend is of great significance for analyzing current policies, formulating correct energy development plans, and promoting the rapid development of China’s national economy.

In this section, we will discuss the domestic energy consumption in China. Domestic energy consumption data often present complex nonlinearity, so the traditional methods of domestic energy consumption analysis are greatly challenged. Aiming at the nonlinearity of domestic energy consumption, this paper establishes SNGM \((1, 1, k, c)\) model to analyze energy consumption, and the results are compared with the traditional NGM \((1, 1, k, c)\) model.

| Year | Data | NGM \((1, 1, k, c)\) | SNGM \((1, 1, k, c)\) |
|------|------|----------------|----------------|
|      |      | Value | RE | APE (%) | Value | RE | APE (%) |
| 2010 | 36470| 36470 | 0.00 | 0.00 | 36470 | 0.0000 | 0.00 |
| 2011 | 39584| 40486.5 | 902.5 | 2.28 | 42358.4 | 52.388 | 0.12 |
| 2012 | 42306| 45512.3 | 584.0 | 1.38 | 44816.7 | 714.20 | 1.57 |
| 2013 | 45531| 51494.5 | 139.55 | 2.79 | 50589.5 | 490.46 | 0.98 |
| 2014 | 47212| 54899.8 | 690.8 | 1.27 | 57725.9 | 105.94 | 0.18 |
| 2015 | 50099| 58614.9 | 994.9 | 1.73 | 57725.9 | 105.94 | 0.18 |
| 2016 | 54209| 62668.1 | 61903.5 | --- | --- | --- | --- |
| 2017 | 57620| 67090.1 | 66548.4 | --- | --- | --- | --- |
| 2018 | 60901| 71914.6 | 71713.0 | --- | --- | --- | --- |
| 2019 | 64003| 77178.0 | 77455.3 | --- | --- | --- | --- |
| 2020 | 67920.4 | 82920.4 | 83840.0 | --- | --- | --- | --- |
| 2021 | 71853.5 | 89185.3 | 90939.0 | --- | --- | --- | --- |
| 2022 | 75820.3 | 96020.3 | 98832.1 | --- | --- | --- | --- |
| 2023 | 103477.0 | 103477.0 | 107608.0 | --- | --- | --- | --- |
At first, Table 4 lists the original data about China’s domestic energy consumption from 2010 to 2017, which is gathered from the National Bureau of Statistics of China. Secondly, we use the data in Table 4 to compute the simulated data from 2010 to 2025 based on the classical NGM \((1, 1, k, c)\) model and SNGM \((1, 1, k, c)\) model proposed in this paper, and the numerical results are also listed in Tables 4 and 5. Thirdly, we draw the forecast and calculate results of the numerical results in Tables 4 and 5, those are shown in Figures 4, 5 and 6. Finally, through the above tables and images, we analyze the accuracy of the calculation of the SNGM \((1, 1, k, c)\) model, use the SNGM \((1, 1, k, c)\) model to predict China’s domestic energy consumption from 2018 to 2025 and analyze the results.

**Table 5.** Measuring indicators for China’s domestic energy consumption (Ten thousand tons of standard coal) among the NGM \((1, 1, k, c)\) model and SNGM \((1, 1, k, c)\) model.

| Indicator | NGM \((1, 1, k, c)\) | SNGM \((1, 1, k, c)\) |
|-----------|----------------------|----------------------|
| MRE       | 821.08               | 357.84               |
| MAPE(%)   | 1.49                 | 0.68                 |
| RMSE      | 919.53               | 423.27               |
| MSER      | 0.0712               | 0.0577               |

**Figure 4.** The forecast of China’s domestic energy consumption based on the NGM \((1, 1, k, c)\) model and SNGM \((1, 1, k, c)\) model.

**Figure 5.** The APE (absolute percentage error) of the NGM \((1, 1, k, c)\) model and SNGM \((1, 1, k, c)\) model for China’s domestic energy consumption.

**Figure 6.** The MRE, MAPE, RMSE and MSER values of two model.

Because the domestic energy consumption data of China is limited, it belongs to small sample data. Therefore, this study chooses NGM \((1, 1, k, c)\) model and SNGM \((1, 1, k, c)\) model in grey system theory predict the domestic energy consumption in China.

In this paper, the traditional NGM \((1, 1, k, c)\) model and the SNGM \((1, 1, k, c)\) model are used to forecast China’s domestic energy consumption from 2011 to 2025 respectively. From the numerical results in Table 5 and Figures 4, 5, and 6, we can know that the MAPE of the SNGM \((1, 1, k, c)\) model is 0.68%, compared with the value of NGM \((1, 1, k, c)\) model is 1.49%. For the SNGM \((1, 1, k, c)\)
model, the value of MRE, RMSE and MSER is 357.84, 423.27 and 0.0577. All error indexes of NGM (1, 1, k, c) model are smaller than the NGM (1, 1, k, c) model. And the absolute percentage error from 2013 to 2017 has been greatly reduced for SNGM (1, 1, k, c) model, but it is unstable for NGM (1, 1, k, c) model. That shows that the SNGM (1, 1, k, c) model has higher prediction accuracy and more accurate prediction results.

Using the SNGM (1, 1, k, c) model, the domestic energy consumption from 2018 to 2025 is predicted and the results are shown in Table 6. And the relative growth rate ($RGR$) and the doubling time ($D_t$) for energy consumption are given as follows [8]

$$RGR = \frac{\ln N_2 - \ln N_1}{t_2 - t_1}$$  \hspace{1cm} (21)

and

$$D_t = (t_2 - t_1)\ln \left(\frac{2}{\ln N_2 - \ln N_1}\right)$$  \hspace{1cm} (22)

where $N_2$ and $N_1$ are energy consumption quantity at $t_1$ and $t_2$.

**Table 6.** Forecast value of China’s annual domestic energy consumption based on SNGM (1, 1, k, c) model from 2018 to 2025.

| Year | 2018   | 2019   | 2020   | 2021   | 2022   | 2023   | 2024   | 2025   |
|------|--------|--------|--------|--------|--------|--------|--------|--------|
| Predicted value | 61903.5 | 66548.4 | 71713.0 | 77455.3 | 83840.0 | 90939.0 | 98832.1 | 107608.0 |
| Growth percentage (%) | 7.24 | 7.50 | 7.76 | 8.01 | 8.24 | 8.47 | 8.68 | 8.88 |
| Relative growth rate | 0.0717 | 0.0724 | 0.0747 | 0.0770 | 0.0792 | 0.0813 | 0.0832 | 0.0851 |
| Doubling time | 3.3283 | 3.3193 | 3.2869 | 3.2567 | 3.2288 | 3.2030 | 3.1793 | 3.1574 |

According to the Table 6, we can see that China’s domestic energy consumption is increasing, and the growth rate tends to becomes faster. The predicted value and growth percentage for China’s domestic energy consumption are listed in Figure 7.

**Figure 7.** The predicted value and growth percentage for China’s domestic energy consumption from 2018 to 2025 based on the SNGM (1, 1, k, c) model.

It can be seen in Table 6 and Figure 7, there is a linear trend of growth for the growing percentage of China’s domestic energy consumption. We can see that China’s domestic energy consumption will be more than 1 billion tons of standard coal in 2025, and the growth percentage is 8.88%. Due to the increase for the relative growth rate of domestic energy consumption in China, China needs less time to double its annual domestic energy consumption in the future. Here are several possible reasons for this phenomenon. On the one hand, with the economic development of China, the living standards of residents have generally improved, thus the consumption of energy will increase significantly. On the other hand, with the increase of China’s population, the consumption of domestic energy will also increase. Finally, due to the increasingly serious aging problem of China’s population, even if the total population of China will decline in the future, the size of the elderly population will be very large due to the characteristics of China’s large population base, and the increase of the elderly population will also lead to an increase in living energy consumption.
From the data of International Energy Agency, we can know due to the impact of the persistent health crisis (coronavirus “COVID19”), the global energy consumption is seriously declining. Although China has won a great victory in fighting the epidemic at the present stage, it will also have a certain impact on China’s energy consumption. Therefore, China’s actual domestic energy consumption may be slightly lower than the predicted value in 2025, but based on the current epidemic situation in China, this error will be very small.

Based on the increasing consumption of domestic energy, we must start to save energy, advocate energy conservation and emission reduction, and call on the authorities to formulate relevant policies to prevent the waste of domestic energy and supervise residents’ energy consumption behavior. And it can effectively reduce domestic energy consumption, further reduce China’s domestic energy consumption, and promote China’s economic development.

5. Conclusions
In this paper, a new discrete NGM (1, 1, k, c) model named SNGM (1, 1, k, c) is proposed and its background value was reconstructed by the Simpson formula. Through the example and predict results, the superiority of the SNGM (1, 1, k, c) model are demonstrated.

In the prediction of domestic energy consumption data, the SNGM (1, 1, k, c) has better performance than classical NGM (1, 1, k, c) model. The SNGM (1, 1, k, c) model has good adaptability to nonlinear data prediction, which provides a powerful method for domestic energy consumption data prediction. We forecast the domestic energy consumption in 2025 by the SNGM (1, 1, k, c) model and analyze the results, which also shows that the energy problem in China is becoming more and more serious. Therefore, it shows the importance and urgency of improving the awareness of energy conservation among residents.

Finally, the SNGM (1, 1, k, c) model has better adaptability to both low-increment exponential increase sequence and high-increment exponential increase sequence, so the calculation should be used for SNGM (1, 1, k, c) model in many areas such as economy, engineering, and self-control system.

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