Research on Energy Supply and Demand Forecast and Carbon Neutralization Path Based on Grey-Monarch Butterfly Optimization Model

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Abstract—Energy and electricity are the key areas for China to achieve the double carbon target, and accurate forecasting of future energy supply and demand and carbon emissions is beneficial to develop a feasible path for low carbon transition. The gray prediction model GM (1,1) is one of the most widely used dynamic prediction models in the field of energy forecasting, but it requires high raw data and the model may fail when the development coefficient of GM (1,1) is large. On the other hand, the gray action of GM (1,1) directly determines the model prediction accuracy, this paper introduces a novel population intelligence algorithm monarch butterfly optimization (MBO), which has excellent performance in practical optimization problems, into the optimization process of gray action of GM (1,1), and proposes a new Gray-Monarch Butterfly optimization prediction model to realize the prediction. By comparing the prediction data with the classical literature, the effectiveness and superiority of the proposed Gray-monarch butterfly optimization prediction model are confirmed. Finally a carbon neutral pathway is given for Tianjin based on the prediction results.

1. Induction

Tianjin City 2021 "Government Work Report" pointed out that: accelerate the implementation of carbon emissions peak action. Develop and implement the carbon emission peaking action plan, and promote key industries such as iron and steel to take the lead in peaking and coal consumption to reach the peak as early as possible. Improve the dual control system of energy consumption, collaborate to promote pollution reduction and carbon reduction, implement dual control of industrial pollution emissions, and promote the green transformation of industry. In order to develop a practical carbon peak action path, it is necessary to make accurate forecasts of Tianjin's future energy supply and demand and carbon emissions, and on this basis to develop a low-carbon transition path for Tianjin.

The grey theory was first proposed by Deng Julong in 1989\textsuperscript{[1]}, has been more than 20 years of history. The theory does not rely on statistical methods to consider grey quantities, but it indirectly uses raw data to identify their inherent regularity. Cumulative generation operation (AGO) is the main idea of grey theory, which originated from cumulative distribution in primary statistics. The purpose of AGO is to reduce the randomness of raw data to a monotonously growing sequence. Grey theory has been widely used in forecasting research because of its higher prediction accuracy compared with other forecasting techniques\textsuperscript{[2-3]}. For the time series that can be approximated by exponential function curve, GM (1,1) can
improve the prediction accuracy to a certain extent, because the traditional grey model is constructed by exponential function. However, the time series of the actual system will have wavy changes, and the prediction accuracy of the traditional grey model is low when dealing with such data. Therefore, many models have been proposed to improve this accuracy, such as Taguchi-grey\cite{4}, gray-fuzzy\cite{5}, triangle-grey\cite{6} and other models\cite{7-10}. Although these hybrid models can improve the prediction accuracy of grey GM (1,1) model to a certain extent, they are difficult to be applied in engineering because they involve complex mathematical calculation.

Influenced by the migration behavior of American monarch butterfly, Wang et al\cite{11} Monarch Butterfly Optimization (MBO) is proposed in this paper. MBO has two operators: the migration operator with local search ability and the adjustment operator with global search ability. In MBO, both the migration operator and the adjustment operator can determine the Monarch search direction at the same time, so MBO is suitable for parallel processing and can balance between strength and diversification. The calculation process of MBO is simple, less calculation parameters are required, and it is easy to be implemented by program. Therefore, MBO is widely used in many fields\cite{12-13}.

GM (1,1) model is based on the accumulated generation sequence, and the least square method is used to solve the model parameters, which will produce two identification parameters: development coefficient a and grey action u. Therefore, the value of GM (1,1) model is an important factor affecting the model error, and directly determines whether the prediction results are normal and reasonable.

GM (1,1) model is exponential model in essence, and there is a certain degree of deviation. When the parameters are small, the corresponding curve of the original sequence is relatively flat, and the fitting degree of the original curve and the curve of the simulated sequence is high, and the error is small. When the parameter is large, GM (1,1) model may fail\cite{14-17}. The grey action magnitude has a dynamic nature that changes with time, which reflects the relationship between data changes. If a better U value can be found and substituted into the model for prediction, the model accuracy will be improved\cite{18}.

In this paper, with a monarch butterfly MBO fusion algorithm and the GM (1, 1) model for a, u two parameters of the model optimization, the objective function of using the algorithm of average error function of MBO, this paper proposes a new grey-monarchs optimization model algorithm, effectively improve the prediction accuracy of grey algorithm and the applicability of wavy time series data, the iteration method is simple, fast convergence rate, easy for engineering implementation.

2. The basic theory

2.1 Basic idea of grey prediction model

Gray prediction is an important part of gray system theory. Gray prediction models process the gray information in incomplete, cluttered small sample data into a kind of clear information to whittle it down, and in the process discover the inherent evolutionary law of the system and get a long-term description of the development of things to achieve fuzzy quantitative prediction of future variables. The commonly used methods are GM (1, 1) model and gray Verhulst model. According to the functions and characteristics of gray prediction models, the prediction models can be classified into the types of series prediction, waveform prediction, interval prediction, catastrophe prediction and system prediction\cite{19-20}.

2.2 GM (1,1) prediction model

GM (1,1) model is the most widely used dynamic model in grey forecasting model. The mathematical modeling steps of GM (1,1) model are as follows:

(1) The processing of the original sequence

Remember the raw number column $X^{(0)}$:

$$X^{(0)} = \begin{bmatrix} x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n) \end{bmatrix} \quad (X^{(0)}(k) \geq 0, \quad k = 1, 2, \ldots, n) \quad (1)$$

right $X^{(0)}$ Do a sum to get the sequence $X^{(1)}(1 - \text{AGO})$:

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i) \quad (k = 1, 2, \ldots n)$$
\[ X^{(1)} = \{x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n)\} \quad (k = 1, 2, \ldots n) \]  \hspace{1cm} (2)

(2) Generate sequence \( X^{(1)} \) The first-order differential whitening equation is established in general and approximately obeying the exponential law:

\[ \frac{dx^{(1)}(k)}{dt} + ax^{(1)}(k) = u \]  \hspace{1cm} (3)

(3) After the least square method is used to obtain the values of identification parameters A and U, the prediction model is as follows:

\[ \hat{x}^{(0)}(k + 1) = \left( x^{(0)}(1) - \frac{u}{a} \right) e^{-ak} + \frac{u}{a} \quad (k = 1, 2, \ldots, n - 1) \]  \hspace{1cm} (4)

(4) The above calculated values are reduced by the following formula to obtain the simulation sequence:

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

\[ x^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)\} \]  \hspace{1cm} (5)

3. Gray-monarch optimization algorithm

In this paper, monarchs MBO algorithm and GM (1,1) model are fused to optimize the a and u parameters of the model. The average error function is adopted as the objective function of MBO algorithm. The smaller the average error value is, the higher the fitness is; otherwise, the lower the fitness is. The objective function can be expressed as:

\[ f(a, u) = \frac{1}{n} \sum_{k=1}^{n} \left| \frac{x^{(0)}(k) - x^{(1)}(k)}{x^{(0)}(k)} \right| \]  \hspace{1cm} (6)

The algorithm flow of the optimization model is as follows:

1. The original data were sorted into sequence, and the simulation sequence and a and u identification parameters of the original sequence were obtained by GM (1,1) model.
2. By analyzing the image morphology of 1-AGO sequence in GM (1,1) model, the value range of a and u can be roughly deduced.
3. The butterfly population is initialized. The position of each butterfly combines the information of a and u parameters, and each butterfly represents a solution of the objective function.
4. According to the original sequence and simulated sequence, the average error function was constructed as the objective function, and the fitness value of the population was calculated and sorted in the initial stage of iteration.
5. Keep individuals with high fitness values were selected and marked as elite individuals.
6. The population was divided into two parts: butterflies in Land1 were updated by migration operator and butterflies in Land2 were updated by adjustment operator.
7. After merging the populations with updated locations, the fitness values were recalculated, and the keep butterflies with poor fitness were taken out and marked.
8. Elite butterflies were used to directly replace the butterflies with poor fitness, and the replaced population was used as the initial population of the next iteration.
9. Mark the individuals with the optimal fitness value of this iteration, iterate, stop the cycle when the maximum number of iterations is reached, and select the optimal individuals from the optimal individuals of each generation as the final optimization result.
4. The example analysis

4.1 Analysis of the correctness and effectiveness of the proposed algorithm

In order to verify the correctness and effectiveness of the proposed algorithm, the proposed algorithm is compared with the prediction results of industrial terminal energy consumption in Tianjin in literature [21].

The parameters of the monarch optimization algorithm used in the calculation example are set as follows: butterfly populationN=500;The two important parameters a and u, which constitute the position of butterfly, are randomly generated within ± 20% of the values of a and u generated by GM (1,1) model respectively.According to multiple calculations, the maximum number of iterations is set to 100, and reaching the maximum number of iterations is the termination condition of the algorithm.Butterfly migration rate is \( p_{m} = \frac{5}{12} \), the migration period is \( peri = 1.2 \) And adjust the rate\( BAR \) The value of and\( peri \)The same value.The number of butterflies in Land1 population is \( \text{ceil}(N \times peri) \), the number of butterflies in population Land2 is \( N - \text{ceil}(N \times peri) \);The longest stride of a butterfly\( maxstep \)Set to 1;The number of butterflies retained as elite individuals in each generation\( keep \)4.

Literature [21] selected the industrial energy terminal consumption in Tianjin from 2000 to 2010 as the original series of the model. Due to the good smoothness of the original series, the overall trend was very consistent with the predicted results of GM (1,1) model, and the prediction effect was good.On this basis, we use the gray-Monarch optimization algorithm proposed in this paper to predict the data series, and the results are as follows:
Tab.1 Forecast of terminal industrial energy consumption in Tianjin from 2000 to 2010 under different forecasting models

| Year | The original data (Ten thousand tons of standard coal) | The model predicted value in reference 21 (ten thousand tons Standard coal) | The predicted value of the algorithm proposed in this paper (ten thousand tons Standard coal) |
|------|-------------------------------------------------------|--------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| 2000 | 1536.83                                               | 1536.83                                                                  | 1536.83                                                                                  |
| 2001 | 1661.88                                               | 1627.87                                                                  | 1628.46                                                                                  |
| 2002 | 1913.61                                               | 1815.69                                                                  | 1816.34                                                                                  |
| 2003 | 1957.09                                               | 2025.18                                                                  | 2025.89                                                                                  |
| 2004 | 2259.61                                               | 2258.84                                                                  | 2259.61                                                                                  |
| 2005 | 2512.38                                               | 2519.47                                                                  | 2520.30                                                                                  |
| 2006 | 2837.56                                               | 2810.16                                                                  | 2811.07                                                                                  |
| 2007 | 3161.39                                               | 3134.39                                                                  | 3135.38                                                                                  |
| 2008 | 3466.51                                               | 3496.03                                                                  | 3497.10                                                                                  |
| 2009 | 3740.57                                               | 3900.56                                                                  | 3900.56                                                                                  |
| 2010 | 4519.17                                               | 4550.57                                                                  | 4550.57                                                                                  |

Table 1 describes the comparison between the predicted value and actual value of industrial energy terminal consumption in Tianjin from 2000 to 2010 by the prediction model in literature [21] and the algorithm proposed in this paper. Both algorithms can accurately predict industrial energy terminal consumption, indicating the correctness of the algorithm proposed in this paper.

Figure 2 is the graph of the data in Table 1, from which the fitting degree of the two algorithms to the real value can be clearly seen, indicating that both the algorithm proposed in this paper and the algorithm in literature [21] can better predict the industrial energy terminal consumption in Tianjin.

Figure 3 said monarch butterfly algorithm of GM (1, 1) model parameters optimization of the average relative error convergence figure, can be seen from figure 3 after 3 times of iteration to converge to below 0.101, after six iterations can be narrowed to 0.1, the average relative errors show that the grey - monarch butterfly algorithm iteration method is simple, fast convergence rate, easy for engineering implementation.

The comparison results between GM (1,1) model in reference [21] and the three accuracy indexes MAE, MAPE and MSRE of GM (1,1) optimization model based on monarch butterfly algorithm proposed in this paper are as follows:

| PRECISION INDEX | GM (1,1) MODEL USING THE MONARCHS ALGORITHM GM (1,1) OPTIMIZATION MODEL |
|-----------------|-------------------------------------------------------------------------|
| MAE             | 56.4084                                                                 |
|                 | 56.1822                                                                 |
| MAPE            | 0.0197                                                                  |
|                 | 0.0191                                                                  |
| MSRE            | 0.0265                                                                  |
|                 | 0.0261                                                                  |
The data results in table 2 show that the GM (1,1) prediction model optimized by the monarch algorithm has higher accuracy, smaller error and better prediction effect than the GM (1,1) model, which can verify the correctness and effectiveness of the proposed method in this paper.

4.2 Specific application of the proposed algorithm

The total primary energy production (million tons of standard coal) in Tianjin from 2020 to 2035 is predicted using the optimized GM (1, 1) model with the imperial butterfly algorithm, assuming that starting from 2021, clean energy substitution is carried out at 4% of the total primary energy production (million tons of standard coal) per year, then the proportion of clean energy substitution of total primary energy production in 2021 is 4%, in 2022 the proportion of clean energy is 8% in 2021, the proportion of total primary energy production replaced by clean energy is 8% in 2022, the proportion of total primary energy production replaced by clean energy is 12% in 2023, and so on, and the proportion of total primary energy production replaced by clean energy is 40% in 2030, which results in the actual value of total primary energy production (million tons of standard coal) after clean energy replacement, and further, the carbon emission conversion factor of standard coal is taken as IPCC Guidelines for National Greenhouse Gas Emission Inventories and the average value of emission coefficient published by the Energy Research Institute of National Development and Reform Commission 0.7517, which leads to the projected values of total primary energy production (million tons of standard coal) in Tianjin from 2021 to 2035, the ratio of clean energy to total primary energy production in that year for each year, total non-clean energy primary energy production in each year and annual carbon emission projections are shown in Table 3 below.

| YEAR | TOTAL PRODUCTION FORECAST OF PRIMARY ENERGY (TEN THOUSAND TONS OF STANDARD COAL) | CARBON EMISSION MEASUREMENT BEFORE CLEAN ENERGY REPLACEMENT (TEN THOUSAND TONS) | CLEAN ENERGY REPLACEMENT RATIO (%) | TOTAL NON-CLEAN ENERGY PRODUCTION (TEN THOUSAND TONS OF STANDARD COAL) | CARBON EMISSIONS AFTER CLEAN ENERGY REPLACEMENT (TEN THOUSAND TONS) |
|------|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------|-----------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|
| 2020 | 6905.30                                                                         | 5190.71                                                                         | 0                                 | 5362.06                                                          | 5529.46                                                          |
| 2021 | 7430.47                                                                         | 5585.48                                                                         | 4                                 | 7133.26                                                          | 5951.30                                                          |
| 2022 | 7995.59                                                                         | 6010.28                                                                         | 8                                 | 7355.94                                                          | 5691.30                                                          |
| 2023 | 8603.68                                                                         | 6467.39                                                                         | 12                                | 7571.24                                                          | 5845.77                                                          |
| 2024 | 9258.02                                                                         | 6959.25                                                                         | 16                                | 7776.73                                                          | 5990.82                                                          |
| 2025 | 9962.12                                                                         | 7488.53                                                                         | 20                                | 7969.69                                                          | 6124.12                                                          |
| 2026 | 10719.77                                                                        | 8058.05                                                                         | 24                                | 8147.03                                                          | 6243.04                                                          |
| 2027 | 11535.04                                                                        | 8670.89                                                                         | 28                                | 8305.23                                                          | 6344.63                                                          |
| 2028 | 12412.32                                                                        | 9330.34                                                                         | 32                                | 8440.38                                                          | 6425.57                                                          |
| 2029 | 13356.32                                                                        | 10309.95                                                                        | 36                                | 8548.04                                                          | 6482.11                                                          |
| 2030 | 14372.11                                                                        | 10803.52                                                                        | 40                                | 8623.27                                                          | 6510.09                                                          |
| 2031 | 15465.16                                                                        | 11625.16                                                                        | 44                                | 8660.49                                                          | 6504.83                                                          |
| 2032 | 16641.34                                                                        | 12509.30                                                                        | 48                                | 8653.50                                                          | 6461.12                                                          |
| 2033 | 17906.96                                                                        | 13460.66                                                                        | 52                                | 8595.34                                                          | 6373.13                                                          |
| 2034 | 19268.85                                                                        | 14484.39                                                                        | 56                                | 8478.29                                                          | 6234.39                                                          |
It can be seen from Table 3 that with the development of economy and society, the total primary energy production (equivalent to million tons of standard coal) in Tianjin continues to rise, and is expected to reach 143,721,100 tons of standard coal in 2030, with carbon emission up to 10,805,200 tons, if 4% of the total primary energy production (equivalent to million tons of standard coal) in Tianjin is replaced by clean energy every year from 2021 onwards, then by 2030 When clean energy accounts for 40% of Tianjin's total primary energy production, Tianjin's total primary non-clean energy production (equivalent to 10,000 tons of standard coal) will drop to 86,232,700 tons, and carbon emissions will peak in 2031 (65,100,900 tons), thus applying the proposed gray-imperial butterfly optimization model algorithm to realize the forecast of Tianjin's total primary energy production and carbon emissions, and according to the forecast results, it gives The proposed gray-monarch butterfly optimization model algorithm is applied to predict the total primary energy production and carbon emission in Tianjin, and a feasible path for Tianjin to reach the carbon peak around 2030 is given based on the prediction results, providing an alternative "Tianjin solution" to achieve the carbon peak in 2030.

5. Conclusion
In this paper, the monarch butterfly optimization algorithm is applied to the traditional gray GM(1,1) forecasting model for the first time, and the gray-monarch butterfly optimization model algorithm is implemented to forecast the energy supply and demand and carbon emissions in Tianjin, and the main conclusions are as follows.

1. When the fluctuation of raw energy data is not large, the prediction effect of both the proposed algorithm and the traditional gray prediction algorithm on the energy supply and demand of Tianjin city is better, and the prediction accuracy of the proposed algorithm is higher and the prediction effect is better, which confirms the correctness and effectiveness of the proposed method.
2. When the original energy data fluctuates greatly, the traditional algorithm cannot predict the energy supply and demand in Tianjin well, and there are certain deviations, but the proposed algorithm can still give good prediction results, and compared with the traditional algorithm, the MAE, MAPE and MSRE errors of the proposed algorithm are significantly reduced, and the prediction accuracy is significantly improved, which confirms the superiority and adaptability of the proposed method.
3. The prediction results of the total primary energy production and carbon emission of Tianjin by the algorithm proposed in this paper show that, by increasing the proportion of clean energy in the total annual primary energy production of Tianjin by 4% from 2021, the primary energy carbon emission of Tianjin will peak in 2031, and the carbon emission is estimated to be 65,100,900 tons, which provides a reference path for Tianjin to achieve the carbon peak in 2030.

Based on the past energy supply and demand situation in Tianjin, this study has made energy supply and demand forecasts for 2020-2035 and given a macroscopic path for Tianjin 2030 to achieve carbon peak, mainly from the perspective of energy structure optimization to give a low-carbon transition path for Tianjin, which requires further analysis of cost and carbon emission levels under typical energy use scenarios based on multi-objective collaborative supply and demand optimization techniques, introduction of constraint method, fuzzy decision theory, etc. It is necessary to further analyze the cost and carbon emission levels under typical energy-use scenarios based on multi-objective supply-demand optimization techniques, introduce constraint methods, fuzzy decision making and other theories, and derive flexible charging and discharging strategies for electric vehicles and other flexible electricity-using devices according to peak and valley time-sharing tariffs, and adopt specific strategies for optimizing the operational efficiency of the energy system by using integrated energy co-generation for heat and energy supply, so as to optimize the near-term planning path for low-carbon transformation in Tianjin under the scenario of lowest energy carbon emission and restricted comprehensive energy cost.

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