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Analysis and Research on the Adjustment of Energy Consumption Structure Based on the "Dual Carbon" Target

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***Abstract*—In response to China's "dual-carbon" goal committed in the Paris Agreement and the United Nations Framework Convention on Climate Change, this paper takes the panel data published in the China Statistical Yearbook 2021 as the object, and studies an application of GM(1,1) combined with weakening buffer filtering as a predictive method for validating "dual-carbon" targets. Through the scenario analysis of adjusting the proportion of energy consumption structure without affecting the development of the economy and people's livelihood, this method can give the feasibility of China's realization of the "dual carbon" goal. The verification results also show that the adjustment method of scenario analysis 2 given in this paper can provide an effective scientific reference way for the government and related industries to realize the "dual carbon" target.**

Key words: carbon peak; carbon neutralization; GM(1,1) model; weakening buffer filter model

I. INTRODUCTION

In recent years, the issue of climate change has become a focus of attention of the international community. The growing carbon dioxide (CO_2) emissions in the production and consumption fields are increasingly leading to global warming and frequent occurrence of extreme weather, such as droughts, tsunamis, heat waves, hurricanes, etc., which have seriously threatened human survival and social development. In order to combat climate change, more than 190 parties signed the Paris Agreement in legal form. It is agreed that by the end of this century, the global average temperature rise will be kept within 2°C relative to the pre-industrial level, and the global average temperature rise will be controlled within 1.5°C. As an active advocate and practitioner of global response to climate change, in order to actively respond to the temperature control goals of the Paris Agreement, China has proposed and announced that its CO_2 emissions will reach the carbon peak by 2030, and strive to achieve carbon neutralization by 2060 as the "dual-carbon" target [3][4]. This goal not only reflects the Chinese government's active response to the international community's carbon emission reduction plan, actively follows the trend of low-carbon development, and jointly undertakes major strategic decisions for global sustainable development, but also fully reflects China's responsibility to address climate change and low-carbon transition issues.

II. CURRENT STATUS OF CARBON PEAK AND CARBON NEUTRALITY

According to the statistics of the Organization for Economic Cooperation and Development, more than 50 countries have achieved carbon peaks ahead of schedule. For example, countries such as the UK, France, Germany and Sweden achieved carbon peaks as early as the 1970s, and countries such as Switzerland, Brazil, the United States, Japan, Canada, Italy and South Korea also achieved carbon peaks between 2000 and 2018. These major developed countries that started industrialization relatively early have now entered the post-industrialization era or the information era, and their economic growth is no longer overly dependent on the growth of energy consumption [5]. To achieve the carbon neutrality goal, more than 130 countries and regions in the world have proposed to achieve the carbon neutrality goal through legal regulations, policy declarations, or submission of UN commitments [6]. For example [7]: Britain, France, Germany, Spain, Hungary, New Zealand and other countries have proposed the goal of achieving carbon neutrality by 2050 in the form of legal regulations; while South Africa, Switzerland, South Korea, Japan, Norway, Portugal and other countries have adopted the policy declaration method to achieve carbon neutrality goals by 2050; The United States, which emits the most per capita GDP, also made a new commitment to achieve carbon neutrality goals by 2050 in 2021. It can be seen that in order to deal with global climate change, countries around the world have basically reached a broad consensus on achieving carbon peak and carbon neutrality.

For CO_2 emissions, the total CO_2 of all continents released by the International Energy Agency (IEA) in 2020 has increased from 11.207 billion tons in 1965 to 34.169 billion tons in 2019, an increase of more than 2 times in 54 years [8]. In 2020[9], China's CO_2 emissions accounted for about 30.7% of the global total emissions. Among them, most of the CO_2 emissions are generated in the process of energy consumption and industrial production, accounting for about 83% of all greenhouse gas emissions. To this end, as the world's largest economy and an economically developing country, China needs to make changes in many aspects of society in order to reach the carbon peak by 2030 and achieve the "dual carbon" vision of carbon neutrality by 2060, such as transforming

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the economic development mode, adjusting the energy structure and industrial structure, changing the public lifestyle, etc.[10]Therefore, in-depth exploration and research on the adjustment of energy structure under China's dual carbon goals is necessary to comprehensively consider economic growth and industrial structure adjustment, as well as effectively analyze and control global carbon emissions, formulate energy strategies, protect the environment, and effectively promote low-carbon economic development, etc. All of these will have important practical significance and reference value.

III. EXISTING RESEARCH RESULTS

At present, the carbon dioxide emissions caused by human activities still mainly come from the traditional consumption of fossil fuels such as coal, oil and natural gas, the proportion of new energy is relatively low. Therefore, under the condition of maintaining the healthy operation and sustainable development of the future economy, how to realize the "dual carbon" goal will obviously face arduous challenges.

Regarding China's "dual carbon" goal of achieving carbon peak and carbon neutrality, the Chinese government has successively issued a series of working opinions and action plans on the "dual carbon" goal, as well as policy documents on climate change. At present, many domestic and foreign scholars have also put forward many emission reduction paths, suggestions or measures to achieve the dual carbon goal, such as: He Jiankun [11] proposed a low-carbon transformation proposal for energy and economy under the "dual-carbon" goal; Zhu Fahua et al. [5] gave a power industry perspective to discuss the development of carbon emission reduction Path; Qi Mengdi et al.[12]gave a low-carbon transformation development proposal from China's petroleum and petrochemical industries; Li Yang et al. [13] gave a nature-based carbon neutral thermal energy solution; Song Xinxin et al. [14] analyze energy saving and emission reduction measures from the perspective of energy self-sufficient sewage treatment plant development; Xu Ding et al. [15] proposed a proposal to build a diversified forest carbon sink product trading mechanism and a diversified forest carbon sink product development mechanism, and Zhang et al. Yan et al. [8] proposed several carbon sink trading suggestions for the development of forestry in Hainan. Obviously, the work of scholars have certain auxiliary reference value for China to formulate decisions and policies to achieve goals in the future. However, what they gave is basically qualitative analysis and suggestions, and lack of theoretical quantitative analysis and prediction of the feasibility of realizing the dual carbon goal. To this end, this paper takes the energy structure panel data from 2010 to 2020 published in the 2021 Yearbook of the National Bureau of Statistics of China as the object, and proposes a prediction model that combines GM(1,1) and weakened buffer filtering. Scenario analysis of carbon emissions and structural proportion adjustment of China's primary energy consumption, verify the feasibility of China's realization of the "dual carbon" goal, and provide a scientific reference for the government and related industries to formulate "dual carbon" goals.

IV. PANEL DATA CARBON EMISSION ANALYSIS

According to the panel data published in the statistical yearbook of the National Bureau of Statistics, China's energy consumption is still mainly composed of fossil fuels such as coal, oil, natural gas and other non-petrochemical energy sources (including hydropower, nuclear power, wind power and solar energy). Although since the "Twelfth Five-Year Plan", China has gradually lowered the proportion of petrochemical energy in the primary energy consumption structure to increase energy conservation and carbon reduction in accordance with consumers' demand, but because China is still in the stage of industrialization and urbanization, economic development tasks are tough, the total demand for energy will continue to grow during a certain period of time. Therefore, the carbon-biased structure of China's energy consumption will inevitably lead to a slow growth trend in CO_2 emissions. For example, the figure below shows the changes in China's energy consumption distribution and CO_2 emissions data from 2010 to 2020 published by the Statistical Yearbook of the National Bureau of Statistics [16].

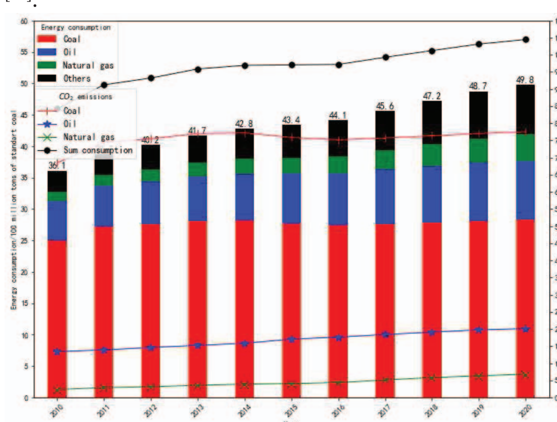

Figure 1. Schematic diagram of China's energy consumption and CO_2 emissions from 2010 to 2020

In the figure, the columns show the proportion of various types of fossil energy consumption. The above data is the total fossil energy consumption; the curve shows the CO_2 emissions and total CO_2 emissions generated by various types of fossil energy consumption according to the carbon emission conversion formula [17]. Obviously, it can be seen from the figure that with the growth of petrochemical energy consumption, CO_2 emissions have increased significantly from 8.416 billion tons in 2010 to 10.44 billion tons in 2020, and the change trend is obviously linear and exponential growth law. Therefore, the use of the representative GM(1,1) model in the grey system theory combined with the buffer filter to adjust and predict the carbon emissions and structural proportions of energy consumption can not only improve their prediction accuracy, but also it can reflect the general law of its changes, and provide a scientific analysis method for policy formulation to achieve China's "dual carbon" goal.

V. PREDICTION MODELS [18][19]

The gray system theory was proposed by Professor Deng Julong, a famous Chinese scholar. It mainly studies the uncertain problem of "small samples and poor information" that cannot be solved by probability statistics and fuzzy mathematics. It can develop and realize the exact description and understanding of the objective world through the generation of "partial" known information. The GM(1,1) model is a commonly used gray model in gray system theory, which can be used for dynamic prediction of a single time series. It has no special requirements for the size of the sample, and does not require any typical distribution law during analysis. At present, it has been widely used in many fields such as agriculture, industry, society, economy, and finance. However, because the GM(1,1) model generally has low prediction accuracy for data with relatively large fluctuations, this paper combines the GM(1,1) model with the gray weakening buffer filter to adjust and predict the total carbon emission of petrochemical energy consumption and its structural proportion, which can effectively solve the impact of uncertain factors in the process of economic development on the prediction accuracy, so as to improve the accuracy of data prediction.

A. GM(1,1) Model

Let $X^{(0)}=(x^{(0)}(1),x^{(0)}(2),\cdots,x^{(0)}(n))$ be a non-negative sequence, $X^{(1)}=(x^{(1)}(1),x^{(1)}(2),\cdots,x^{(1)}(n))$ is the generated sequence obtained by the 1-AGO of $X^{(0)}$, and is the generated sequence of the adjacent mean of $Z^{(1)}=(z^{(1)}(2),z^{(1)}(3),\cdots,z^{(1)}(n))$, then

$$x^{(0)}(k)+az^{(1)}(k)=b \qquad (1)$$

is called is GM(1,1) model. The parameter $-a$ in the model is the development coefficient and b is the gray action quantity. Then,

$$\frac{dx^{(1)}}{dt}+ax^{(1)}=b \qquad (2)$$

is the whitening equation of the GM(1,1) model. It is solved as

$$\hat{x}^{(1)}(t)=(x^{(0)}(1)-\frac{b}{a})e^{-at}+\frac{b}{a} \qquad (3)$$

Therefore, the restored value can be obtained as:

$$\hat{x}^{(0)}(k+1)=(1-e^{a})(x^{(0)}(1)-\frac{b}{a})e^{-ak},$$
$$k=1,2,\cdots,n\text{。} \qquad (4)$$

Among, $x^{(1)}(i)=\sum_{i=1}^{i}x^{(0)}(i)$,

$$z^{(1)}(k)=0.5(x^{(1)}(k)+x^{(1)}(k-1)),$$
$$k=2,3,\cdots,n\text{。}$$

B. Weakening buffer filter model

Because the total CO_2 emissions from petrochemical energy consumption are often affected by many uncertain factors, such as economic policies, industrial structure adjustment, economic crisis, natural disasters, the new crown epidemic and other factors, it is easy to cause large fluctuations in energy consumption, thus affecting the prediction of CO_2 emissions. Therefore, in order to improve the prediction accuracy of the GM(1,1) model, it is necessary to perform weakening buffer filtering on the panel data of the total CO_2 emissions and the proportion of petrochemical energy consumption structure firstly.

The model assuming that the total CO_2 emissions from once consumption of petrochemical energy oscillates around its actual value is

$$z(k)=x_0(k)+\varepsilon(k),\quad k=1,2,\cdots,n$$

Among them, $x_0(k)$ is the actual value of the emission in the year k, and $\varepsilon(k)$ is the random noise influenced by uncertain factors, which is assumed to obey a normal distribution. Then, the corresponding random oscillation sequence is:

$$X=(z(1),z(2),\cdots,z(n)) \qquad (5)$$

Taking its weighted mean, a new stochastic oscillation sequence can be obtained:

$$Y(k)=(\sum_{j=1}^{i}z(k))/i=x_0+(\sum_{j=1}^{i}\varepsilon(k))/i \qquad (6)$$

Obviously, the newly generated sequence can not only weaken the randomness of the original sequence, but also effectively suppress the randomness of $Y(k)$ data.

VI. MODEL VALIDATION AND SCENARIO ANALYSIS OF THE "DUAL CARBON" TARGET

A. Model Validation

Taking the total carbon emission panel data from 2010 to 2016 published in the Statistical Yearbook of the China Bureau of Statistics [16]as the object, and then presenting the traditional linear regression model, GM(1,1) model and the improved prediction model of combining weaken buffer filter with GM(1,1) respectively to compare the prediction results of CO_2 emissions from 2017 to 2020. The verification results are shown in Figure 2.

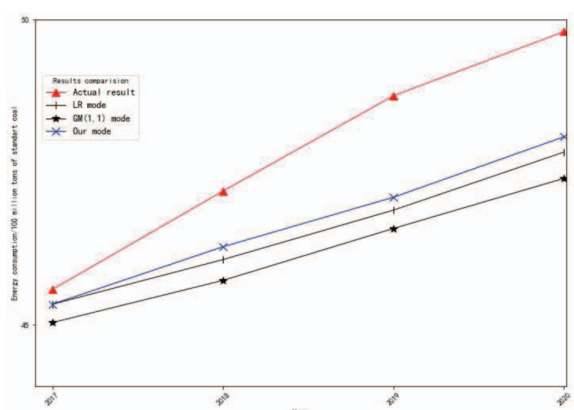

Figure 2. Comparison of total CO_2 emissions predicted by different models

It can be seen from Figure 2 that the prediction accuracy of the prediction model combining GM(1,1) and weakened buffer filter is better than the traditional linear regression model(LR model) and GM(1,1) model. It indicates that the model method given in this paper is effective and feasible for forecasting CO_2 emissions.

B. Scenario analysis of the "dual-carbon" target

Scenario Analysis 1: Assuming that China's energy consumption structure is based on the current policy scenario, the initial CO_2 emission data is based on the panel data from 2016 to 2020. Then, by applying the improved prediction model of combining weaken buffer filter with GM(1,1) in this paper, the total energy consumption and structural proportion of China from 2021 to 2060 can be predicted, as well as the changes in CO_2 emissions, as shown in the figure 3. Obviously, if no policy adjustments are made to the subsequent energy consumption structure according to scenario analysis 1, China's energy consumption will not be able to achieve the carbon peak target before 2030, and it will not be able to achieve carbon neutrality before 2060.

Scenario Analysis 2: According to the statistical yearbook of the National Bureau of Statistics, in China's primary energy consumption structure, coal and oil are still the first and second largest sources of CO_2 emissions. Although coal consumption has been reduced from 72.4% in 2005 to 56.8% in 2020, which is equivalent to an annual reduction of 1.6%, and oil consumption has basically remained fluctuating around 18%, the total amount of CO_2 emissions generated is still increasing from 6.28 billion tons in 2005 to 10.44 billion tons in 2020. Therefore, in order to realize the “dual carbon” goal, scenario analysis 2 assumes that the structural proportion of fossil energy consumption can be adjusted in three stages, as shown in Table 1.

TABLE I Adjustment of the proportion of energy consumption structure in Scenario Analysis 2

Stage	Year	Coal proportion (%)	Oil proportion (%)	Natural gas proportion (%)
First stage	2021-2025	/	/	2
	2026-2030	-2	- 2	4
Second stage	2031-2040	-8	-5	-2
	2040-2050	-10	-8	-3
Third stage	2050-2060	-11	-9	-4

That is, the first phase of adjustments can be implemented in two 5-year plans. In the first five years (2021-2025), due to the current world affected by the new crown epidemic, the adjustment of energy consumption structure may face certain difficulties. However, domestic industries such as industry and electricity still rely heavily on coal, oil and natural gas consumption. Therefore, during this period, the proportion of coal and oil energy consumption can be left unchanged according to the current policy scenario, and the proportion of natural gas consumption can be increased year by year at a growth rate of 2% to meet the growing demand for energy consumption in the economy and people's livelihood; starting from the second five years (2026-2030), coal and oil, which emit the largest CO_2 emissions, will be adjusted year by year at a declined rate of -2%, and the energy consumption gap generated by the adjustment can be supplemented by increasing new energy and renewable energy. Besides, natural gas with relatively small CO_2 emissions can be supplemented. As shown in Table 1, the adjustment to the proportion of natural gas consumption increases year by year at a growth rate of 4%. Obviously, as shown in Figure 3, if the proportion of energy consumption structure is adjusted according to the above method, the carbon peak can be reached in 2025, with a peak value of 10.758 billion tons, taking the lead in realizing the goal of “carbon peak” before 2030.

The second stage (2031-2050) can be adjusted according to two 10-year plans. The first 10-year (2031-2040) is called the transition period, which is the transitional adjustment to the "carbon neutrality" target under the 2^{o}C temperature rise scenario; The two 10 years (2041-2050) are called the realization period, which is to realize the adjustment to the "carbon neutral" temperature control target under the 2^{o}C temperature rise scenario. During the transition period, with the continuous development of new energy technologies and the gradual implementation of industrial transformation and upgrading, the proportion of coal, oil and natural gas consumption can be reduced by -8% , -5% and -2% year by year through appropriate strengthening policy scenarios.. In this way, by 2040, the total CO_2 emissions of China's petrochemical energy consumption can be reduced to about 6 billion tons; in the realization period, the decarbonization of energy consumption can be accelerated, and the proportion of coal, oil and natural gas consumption can be further decreased year by year of -10%, -8% and -3% respectively. As a result, the total CO_2 emissions from petrochemical energy in China can be reduced to about 2.6 billion tons by 2050, reaching the “carbon neutrality” target under the 2^{o}C temperature rise scenario. This is consistent with the non-fossil energy accounting for more than 70% of primary energy consumption in 2050 discussed in the article [7], and the PPT report on long-term low-carbon development goals and strategic research ideas in 2050 by He Jiankun [20]. The proposal that China's energy-related carbon emissions will drop to around 2.9 billion tons under the 2^{o}C temperature rise scenario is basically the same. This has laid a solid foundation for China to further achieve the temperature control target under the 1.5^{o}C temperature rise scenario agreed in the Paris Agreement.

The third stage (2051-2060): in order to achieve the "carbon neutral" temperature control target under the 1.5^{o}C temperature rise scenario, China should further accelerate the deep decarbonization of the energy system. On the basis of 2050, the proportion of coal, oil and natural gas consumption can be further reduced by -11%, -9% and -4% year by year, so that the proportion of petrochemical energy consumption in China will drop to about 9% in 2060. The total CO_2 emission will drop to about 1.2 billion tons. Obviously, this result is also consistent with the recommendations given by Wen [6] and

He Jiankun [20] to achieve the "carbon neutral" temperature control target under the 1.5ºC temperature rise scenario.

There are still about 1.2 billion tons of CO_2 emissions to deal with. The feasible suggested measures are as follows: (1) According to the source data of agroforestry, the storage of CO_2 is about 12 tons per hectare of a single-plant forest, and the storage of CO2 is about 32 tons per hectare of forest with biodiversity. At present, China's agroforestry absorbs about 0.8 to1 billion tons of CO_2 per year [10]. Therefore, the coverage area of afforestation in China can be increased year by year; (2) develop renewable energy vigorously, such as wind energy, solar energy, biomass energy, ocean energy, geothermal energy and other renewable alternative energy sources, as well as develop carbon sinks, carbon capture and storage technologies; (3) develop innovative industrial technologies Vigorously such as green digital and digital economy, and guide social lifestyle changes such as low-carbon consumption and green travel. In this way, the remaining CO_2 emissions can be dynamically processed or transformed and absorbed, and it is expected to finally realize the "dual carbon" goal promised by China in the "United Nations Framework Convention on Climate Change".

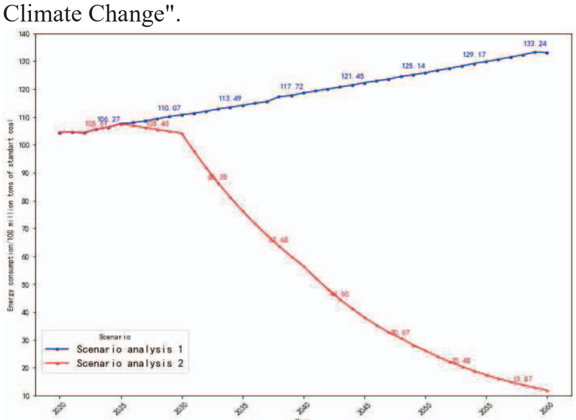

Figure 3. Predicted CO_2 emissions by adjusting energy structure in scenario analysis

VII. CONCLUSION

With the economic growth and development of various countries, the carbon emissions have increased significantly, and the greenhouse effect has become one of the hot issues of global concern. In order to realize the transformation of low-carbon development and reduce CO_2 emissions, countries around the world are currently formulating relevant emission reduction targets on the "United Nations Framework Convention on Climate Change". Therefore, in order to achieve the "dual carbon" goal that China has committed in the United Nations Framework Convention on Climate Change, this paper studies a scenario analysis and prediction method for adjusting energy consumption structure, which can provide an effective scientific analysis reference way for the country to formulate relevant carbon emission legislation, adjust and optimize the industrial and energy structure, and grasp the growth trend of carbon emissions.

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