Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 4126074, 8 pages
https://doi.org/10.1155/2022/4126074

Research Article

Research on the Optimization Strategy of the Low-Carbon Economic Development Model based on the BP Neural Network Model

Yufeng Zhang,[1] Xun Tang,[2] and Jianfei Yang[1]

[1]*School of Economics and Management, Northwestern University, Xian 710000, Shanxi, China*
[2]*Changchun Rudder Investment Group Co. Ltd, Changchun 1300000, Jilin, China*

Correspondence should be addressed to Jianfei Yang; yangjianfei@nwu.edu.cn

Received 15 August 2022; Revised 21 August 2022; Accepted 1 September 2022; Published 22 September 2022

Academic Editor: Baiyuan Ding

Low-carbon economy has become a topic of great concern to the international community. Sea level rise caused by climate change, flood disasters, biodiversity reduction, global famine, and other issues have begun to threaten the normal survival of human beings, and the climate problem needs to be solved urgently. While ensuring rapid economic development, in order to better control the total amount of greenhouse gas emissions, this paper, based on the theory of low-carbon economy, takes control of total carbon emissions for low-carbon economic development, as a perspective, and selects the optimization for the development of low-carbon economy. From the aspects of structural emission reduction technology and emission reduction, a carbon emission control optimization index system for low-carbon economic development based on total carbon emission control is constructed. Under the framework of the index system, construct an optimization model for the total amount of carbon emissions in a low-carbon economy and use the BP neural network model to seek the balance point between economic development, energy consumption, and carbon emissions so as to promote the rational and scientific development of the low-carbon economy. *Planning and development.* First of all, on the premise of maintaining the same economic growth rate, the optimization plan will reduce carbon emissions. Secondly, on the premise of keeping the cost of energy consumption unchanged, it is more reasonable to adjust the energy consumption structure. Taking the optimization plan as the suggestion for the development direction of the low-carbon economy, it provides scientific and feasible technical support for achieving the emission reduction target of reducing the unit greenhouse gas emission to 40%.

1. Introduction

The proposal of a low-carbon economy can basically be considered as the first proposal by the United Kingdom when the institutional framework of the United Nations Climate Change Conference suffered setbacks, especially the Kyoto Protocol, which was subject to unprecedented doubts. On February 24, 2003, the then Prime Minister of the United Kingdom, Tony Blair, published a white paper entitled, The Future of Our Energy: Creating a Low-Carbon Society. Its overall goal is to cut carbon dioxide emissions by 60% from 1990 levels by 2050, fundamentally transforming the UK into a low-carbon economy. The publication of the white paper marks the birth of a new economic development model, which means that economic development cannot be at the expense of resources and the environment, and the government can guide business incentives to encourage the market to use new low-carbon technologies to promote the entire economy. *Structural transformation.* The more positive significance of the white paper is to break the deadlock in international climate negotiations, focus on the mutual promotion and integration of national economic development and global climate change, promote the construction of the foundation of the international climate system, and build a bridge for mutual understanding between developed and developing countries.

Although the United Kingdom took the lead in proposing the concept of low-carbon economy and clarified its

own goals and schedule for realizing low-carbon economy, it did not define the concept of low-carbon economy in detail nor did it provide an indicator system for measuring and evaluating low-carbon economy. The widely cited definition of low-carbon economy is that of the elaboration of British environmental expert Rubinster who stated that low-carbon economy is an emerging economic model, the core of which is based on market mechanisms, through the formulation and development of institutional frameworks and policy measures. Innovation promotes the development and application of energy efficiency technology, energy-saving technology, renewable energy technology, and greenhouse gas emission reduction technology and also promotes the transformation of the entire social economy to a model of high energy efficiency, low energy consumption, and low carbon emissions [1]. In 2009, the China Council for International Cooperation on Environment and Development released a study on China's development of low-carbon economy, arguing that a low-carbon economy is a new economic technology and social system, which can save energy in production and consumption compared with the traditional economic system, reduce energy consumption, and reduce energy consumption and greenhouse gas emissions, while maintaining the momentum of economic and social development [2]. Other scholars [3–7] have also defined the connotation of low-carbon economy, no matter what the definition of low-carbon economy is, its essence is to improve energy efficiency, and the core of the issue of clean energy structure is to achieve clean and sustainable economic and social development through energy technology innovation and policy innovation, taking into account economic development and global climate issues. Based on the above viewpoints, this paper believes that low-carbon economy is an increasingly serious problem faced by human society. It is a brand-new development concept put forward by the global climate issue. While attaching importance to reducing greenhouse gases, it fully respects the needs of economic development of various countries and uses technological revolution and policy innovation as the main means to guide the economy to low energy consumption, low pollution, and low emissions. The direction of development is in line with the needs of sustainable development and ecological balance.

In general, the understanding of the connotation of low-carbon economy can be considered that the focus of low-carbon economy is low-carbon, and the purpose is development, which mainly includes three situations: the first situation is that the growth rate of greenhouse gas emissions is less than the growth of GDP; the second scenario is zero emissions, that is, carbon emissions and carbon sink construction are offset each other; the third scenario is absolute carbon emissions reduction. Of course, the preconditions for the above three scenarios are economic development; that is, the GDP is greater than zero. For developed countries, the goal should be an absolute low-carbon economy, reducing carbon emissions. For developing China, the goal should be relatively low-carbon development. Low-carbon economy is to seek a long-term global level sustainable development [8–12]. Countries should achieve low-carbon economic development in multiple ways according to their own national conditions and achieve the ultimate goal of the Convention: to stabilize the concentration of greenhouse gases in the atmosphere at a level that prevents the climate system from being threatened and disturbed. In view of the great significance of the low-carbon economy, the transition to a low-carbon economy has become a major trend in the development of the world economy. Countries such as France, Japan and Canada have taken corresponding policy measures and actively develop a low-carbon economy. Although the United States does not explicitly accept or oppose the concept of a low-carbon economy, it has always advocated solving the problem of climate change through technological means, which is consistent with the connotation of a low-carbon economy. At the annual meeting of the World Economy in Davos, Switzerland, 2008, the issue of climate change and the handling of the global financial crisis have become the top issues of the annual meeting. The international community has gradually realized that the fundamental way to solve the problem of climate change lies in cutting off economic growth and greenhouse gas emissions and to establish a low-carbon economic development model.

The core of the low-carbon economy is the technological innovation of energy emission reduction. The innovation of the industrial structure system and the transformation of the concept of human survival and development are essentially the problems of improving energy efficiency and clean energy structure. Although the UK has proposed the concept of low-carbon economy, it has not defined low-carbon economy. The concept of economy [13] gives an indicator system that can be compared, and the general understanding of low carbon can be divided into three situations: (1) the growth rate of greenhouse gas emissions is less than the growth rate of DGP; (2) zero emissions; and (3) reduction of absolute emissions. Positive economic growth (GDP growth rate greater than zero) is a prerequisite for realizing low-carbon development. For developed countries, an absolute low-carbon economy should be the goal. For developing countries, relative low-carbon development should be the development goal. How to develop a low-carbon economy and explore the development path of low-carbon economy are the key links in the study of low-carbon economy at this stage, and it is also the most controversial field.

Based on the theory of low-carbon economy and from the perspective of total carbon emission control in the development of low-carbon economy, this paper selects the optimal indicators for the development of low-carbon economy based on the types of energy consumption in economic structure from structural emission reduction, technical emission reduction, etc. In terms of carbon emission control, a low-carbon economy development carbon emission control optimization index system based on total carbon emission control is constructed. The balance point is sought between consumption and carbon emissions so as to promote the rational and scientific planning and development of low-carbon economy.

2. Background

2.1. BP Neural Network. In 1943, McCulloch et al. reinduced and expanded the basic characteristics of neurons, forming the prototype of neural network. The most basic component of the human brain is neuron organization. The interconnection model of brain-like machines is mainly based on the characteristics of biological neurons. This conceptual model can be applied to logical operating systems and has been used since then. Computer expert McCarthy extended the concept of artificial intelligence in the 1950s [14]. However, the research of traditional artificial intelligence methods fell into a low point after a series of changes. In the early 1980s, Hopfield published two articles based on artificial neural networks, which attracted the attention of experts and scholars in the field. This broke the previous low tide period and continued further research on artificial intelligence methods. In late 1986, experts and scholars found that the original system was not applicable in some fields, and disciplines such as machine learning artificial neural networks can effectively make up for traditional artificial intelligence. Due to the shortcomings of intelligent methods, artificial intelligence has entered a new era. As one of artificial intelligence methods, artificial neural network can best reflect its far-reaching impact. Liu et al. used the BP neural network model to better predict the precipitation in Hexi in summer [15]. Zhang studied the GDP data of Guangxi from 1996 to 2010, added a momentum term to the BP neural network for improvement, and changed the learning rate to analyze the performance [16]. Yuan Shuai et al. studied Hunan from the perspective of multidimensional factors. Based on the provincial poverty measurement standard, the spatial distribution results are simulated by the BP network and compared with the remote sensing data to provide a reference for regional poverty alleviation [17]. The related risks also include nonfinancial factors, and a new model is constructed by adding BP neural network to promote sustainable innovation of enterprises [18].

The BP neural network is an algorithm that calculates the error and propagates the error in the opposite direction of the network calculation. The simplest BP neural network has three layers. There is no connection between neurons in a single layer, and there is no direct connection between the input layer and the output layer. The BP neural network algorithm is one of the most widely used neural network models. It is a multilayer feedforward network whose main feature is error backpropagation. It is used to learn and memorize a large number of mapping relationships between input and output models without prior disclosure description. Its learning rule is the steepest descent method, in which backpropagation is used to adjust the BP neural network model. Figure 1 shows the model structure of the BP neural network.

The BP learning process is divided into two steps: (1) Forward propagation of the working signal: the input signal is propagated from the input layer to the output layer through the hidden layer. During the forward propagation of the working signal, the weight and offset values of the network are constant. The state of neurons in each layer will only affect the neurons in the next layer. In the case that the output layer cannot achieve the expected output, it can be switched to the backpropagation of the error signal. (2) The inverse of the error signal backpropagation: The difference between the actual output and the expected output of the network is defined as the error signal. In backpropagation, the error signal propagates from the output to the input layer in a hierarchical manner. During the backpropagation of the error signal, the weights of the network are adjusted by the error feedback. Through the continuous modification of the weights and offsets, the obtained network output is getting closer and closer to the expected output.

In a BP neural network, the activation function of a neuron is a simulation of the mathematical process between the layers of the neuron. The mathematical function reflects the relationship between the layers. In the traditional three-layer BP neural network, the most commonly used activation function is the standard sigmoid function. The mathematical expression of the standard sigmoid function is as follows:

$$g(x) = \frac{1}{1 + e^{-x}}. \tag{1}$$

2.2. Analysis of Economic Development Rights and Emission Reduction Responsibilities. In order to achieve the goal of reducing greenhouse gas emissions, a binding climate agreement should include more participants and clearer sharing of responsibilities. China should adhere to the fair distribution of initial emission rights and its own economic development needs when participating in international emission reduction cooperation. Calculate the responsibility of each country according to the historical cumulative consumption emissions and determine the emission reduction capacity of each country according to the per capita income of each country and the size of the people who can afford it. It is recommended to use the value of the country with the lowest annual per capita cumulative consumption emission stipulated by the Kyoto Protocol as the standard value. Countries that are higher than the standard value implement the limit target, and countries that have not yet reached the standard value implement voluntary emission reduction. The more voluntary emission reductions are made, the further it can be delayed to join the cap. In addition to clarifying their own emission reduction responsibilities, they should also strengthen technical cooperation with developed countries, seek more financial support, advocate the removal of any barriers to technology transfer required for emission reduction, do a good job in collecting and providing emission reduction information and inventory, and develop and implement measures to mitigate and adapt to climate change.

When there is no international agreement on emission reduction, China insists on taking carbon emission intensity as its emission reduction target, which not only reflects the determination of emission reduction, as a responsible major country, but also safeguards the needs of its own economic development. China's economic construction is still in the

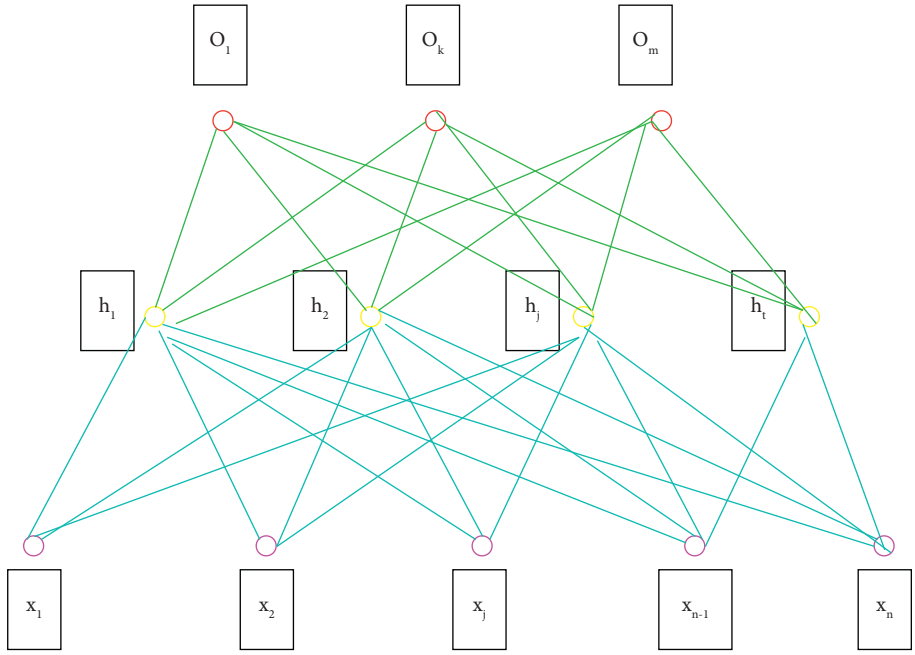

Figure 1: BP neural network structure.

process of industrialization, the transformation of the economic structure is facing many difficulties, and carbon emissions are bound to increase rapidly in the short term. Figure 2 shows the carbon emission intensity of various countries. Among them, China and India have the largest carbon emission intensity, which is much higher than the world average level, but the difference is that India's carbon emission intensity changes gradually, while China's carbon emission intensity curve changes rapidly after a rapid decline. In 2005, China's carbon emission intensity was 27,490 tons per 100 million yuan. In 2020, the carbon emission intensity l dropped by 40–45%, and the approximate range is 1.51–1.65. This data show that China's emission reduction pressure is still very high. Therefore, the development of a low-carbon economy and reducing carbon emissions is the key path for China to fulfill its emission reduction commitments.

2.3. Influencing Factors of Low-Carbon Economic Development in the ISM Model. The low-carbon economy is an economic model based on low energy consumption, low pollution, and low emissions. The essence is the efficient use of energy, the development of clean energy, and the establishment of a low-carbon life model. For China in the stage of industrialization, the development of a low-carbon economy means the transformation of the industrial structure, technological innovation and application in many industries, changes in land use patterns, and the enhancement of residents' low-carbon awareness. Involving the government, enterprises, institutions, and individuals, its complexity and system urgently require an efficient framework to clarify the structural relationships and constraints among the influencing factors of a low-carbon economy. This paper uses a combination of literature search and expert consultation to list and analyze the following eight factors hindering the development of China's low-carbon economy: (1) extensive economic development; (2) lack of a perfect low-carbon policy framework; (3) the population base is large, and the residents' low carbon awareness is weak; (4) insufficient low-carbon technology and management experience; (5) the energy structure needs to be improved urgently; (6) there is an extreme shortage of professionals in the low-carbon field; (7) there is a lack of a sound carbon emission trading mechanism; and (8) the investment is large and financing is difficult.

System Explanation Structural Model (ISM) is a system analysis method developed by Professor Warfield of the United States in 1973 to analyze complex social and economic systems. The method is mainly based on directed graph models and Boolean matrices. The system is decomposed into several subsystem elements, using people's practical experience and knowledge and the help of computers, and finally constitutes a multilevel hierarchical structural model. The idea is transformed into an intuitive model with good structural relationships. It is especially suitable for system analysis with many variables and complex relationships and unclear structure and can also be used for the sorting of programs. The explanatory structural model method is a widely used method in modern systems engineering. This analysis method is a kind of structural modeling technology, and its application is very wide from international issues such as energy issues to regional economic development, enterprises and institutions, and even personal issues. Figure 3 is a hierarchical structure diagram of influencing factors of low-carbon economy. As can be seen from Figure 3, the four main factors affecting the

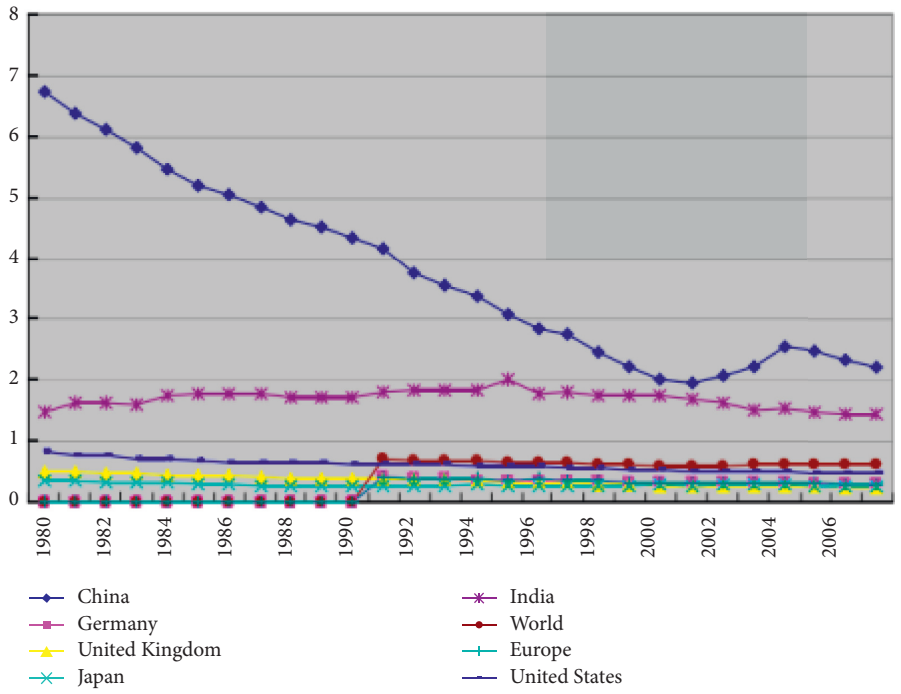

Figure 2: Comparison of carbon emission intensity across countries.

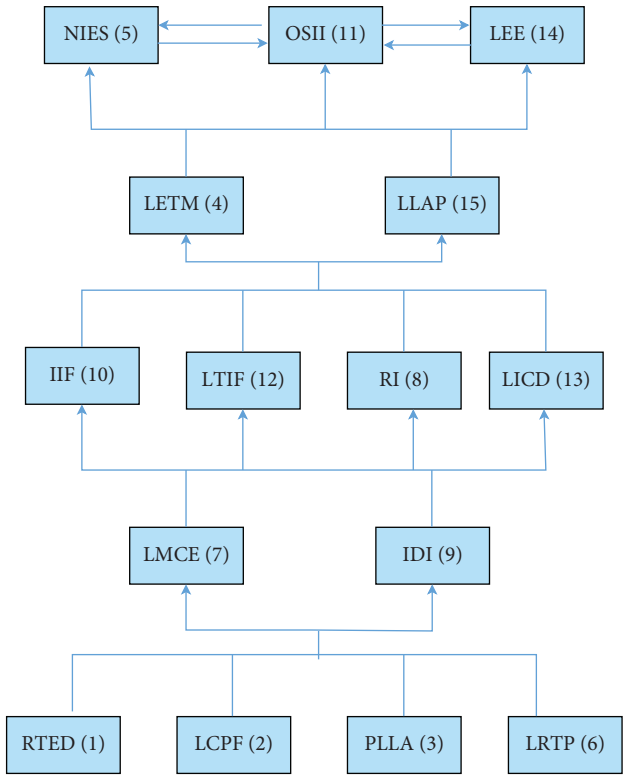

Figure 3: Hierarchical structure of influencing factors of low-carbon economy.

development of China's low-carbon economy are the fourth level in the ISM analysis, namely, extensive economic development (RTED), lack of a perfect low-carbon policy framework (LCPF), a large population base, and the low carbon awareness of residents (PLLA) and the lack of professionals in the low carbon field (LRTP).

3. Research on the Optimization Strategy of the Low-Carbon Economic Development Model based on the BP Neural Network Model

The carbon sinks of China's terrestrial ecosystems are mainly related to the increase of plantation forests in China, regional climate change, fertilization effects of increased carbon dioxide concentration, enhanced natural vegetation activity, and vegetation restoration. This conclusion not only shows the huge carbon sink function of China's terrestrial ecosystems in absorbing or offsetting greenhouse gas emissions, which in turn becomes the scientific basis for China to formulate greenhouse gas emission reduction policies but also explains to a large extent China's current and future prospects. For decades, through various measures to increase sinks, the carbon sequestration potential of terrestrial ecosystems and the huge potential of mitigating and responding to climate change have been utilized. Combining existing research and the characteristics of China's carbon sink, this study uses the following formula to calculate China's carbon sink:

$$C_{\text{sink}} = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} \lambda_i S_i. \quad (2)$$

In the formula, C_{sink} is China's carbon sink; n is the number of carbon sink types; C_i is the carbon sink of the i-th type of carbon sink in tons of carbon equivalent; λ_i is the carbon sink coefficient of the i-th type of carbon sink; and S_i is the effective area of the i-type carbon sink. The actual

carbon emissions and carbon sink estimation parameters are shown in Table 1.

Over the past 30 years of reform and opening up, China has been in the process of rapid industrialization, and carbon dioxide emissions have maintained a rapid growth trend. The situation of controlling and reducing carbon dioxide emissions is very serious. The consumption of fossil energy is one of the important reasons for the increase of carbon dioxide. The factorization methods commonly used in environmental and energy economics can be roughly divided into two categories. One is the structural factor decomposition method (SDA) based on the input-output table, and the other is the exponential factor decomposition method (IDA). Compared with the SDA method, which requires input-output table data as support, the IDA method is more suitable for decomposing models containing time series data and less variable factors because it only needs the data of the research department and is widely used in environmental energy economic research. In summary, the basic form of IDA is as follows:

$$F = \sum_{i=1}^{n} X_{1i} X_{2i} \ldots X_{\mathrm{ni}}. \tag{3}$$

Among them, F represents the object to be decomposed, such as indicators including carbon emissions, energy intensity, or energy consumption; X represents n factors that have an impact on F, and i represents the indicators of different industrial categories, different energy types, or different regions. Exponential decomposition generally takes time series data as the object and examines the influencing factors behind the changes of variables in different periods. The BP neural network model and IDA are used to forecast , and the obtained results show the different calculation results of China's energy demand and carbon emissions in each period from 2020 to 2050. The predicted results are shown in Table 2.

As can be seen from the above table, the total terminal energy demand in 2050 will be 40.01 billion tons of standard coal . Due to the 5th-level influencing factors in the ISM analysis, namely, RTED, LCPF, PLLA, and LRTP, the end sector implements effective energy-saving measures, and the low-carbon scenario reduces the total energy demand by 850 million tons of standard coal compared to the base scenario. Under the setback scenario, the progress of energy-saving measures is unfavorable, the implementation of low-carbon technologies is hindered, and the energy intensity remains high. Compared with the base scenario, the final energy demand increases by 140 million tons of standard coal. CO_2 emission in 2050 is equivalent to 3.546 billion tons of carbon . Compared with the CO_2 emissions of the low-carbon scenario and the base scenario, it will decrease significantly after 2030, peak between 2030 and 2040, stabilize and have a downward trend from 2040 to 2050, and the total emissions by 2050. Volume decreased by 20%. Due to the hindered adjustment of the energy structure ratio in the frustrated scenario, carbon emissions increase by 420 million tons of carbon equivalent compared with the base scenario. There is no CO_2 peak before 2050, which will undoubtedly greatly increase the cost of energy conservation and emission reduction in China and the difficulty of economic transformation.

Table 1: Estimated parameters of carbon emissions and carbon sinks.

Carbon emission factor	Average carbon sink coefficient			
	Wetlands	Arable land and crops	Forest	Grassland
0.7194	30	110	189	110

Table 2: The predicted results of the model.

	2020	2030	2040	2050
GDP per capita ($)	7560	15833	26307	35464
Carbon dioxide emissions (10^6t)	2604	3060	3702	4001
Total energy consumption (Mtcc)	4539	5082	5516	5913

4. Model Prediction Results Analysis

Based on the results predicted by the BP neural network model, it can be known that the change in energy demand has increased rapidly from 1.157 billion tons of standard coal in 2005, and after reaching the peak between 2020 and 2030, the decline rate is slow, and it stays at a relatively long time. In order to meet economic development, under the condition of slow development of new energy, oil demand has also increased significantly. Between 2020 and 2050, oil demand will triple and peak between 2040 and 2050. Although the quantity of hydropower, nuclear power, natural gas, and other new energy sources is also increasing, their speed is slow and far behind that of coal and oil increase. By 2050, coal will account for 42% of primary energy demand, oil will account for 32%, natural gas will account for 9%, nuclear power will account for 6%, hydropower will account for 7%, and other new energy sources will account for 4%.

At present, China is in a critical stage of transition from a resource-dependent economy to a low-carbon economy, and many difficulties and challenges lie ahead for policymakers. As an important part of low-carbon economy research, scenario analysis provides prediction and verification basis for the development path of low-carbon economy. The model in this paper constructs the characterization of China's low-carbon economy development level, which refers to the framework and parameter setting of scenario analysis to quantitatively simulate the development trend of China's low-carbon economy in 2050. From the model results, the following conclusions can be drawn:

(1) The establishment of indicators to characterize the development level of China's low-carbon economy is based on carbon sources. This model can not only accurately and systematically reflect the carbon cycle characteristics of low-carbon development but also reflect the development goals of low-carbon economy, which is convenient for prediction and evaluation. It also analyzes the emission reduction potential from four aspects: increasing the speed of carbon sink

construction, reducing carbon consumption, which mainly refers to reducing the rapid development of fossil energy, strengthening the proportion of carbon utilization and transformation, and developing carbon capture and storage technologies.

(2) Different economic development paths and policy orientations have a great impact on energy demand and carbon emissions. Future energy demand and carbon emissions are likely to fluctuate within a large range. Based on the analysis of factors affecting the development of low-carbon economy, different policies and implementation efforts are to be formulated. According to the results of scenario analysis, by 2050, China's terminal energy demand under the low-carbon scenario will be around 5.2 billion tons of standard coal. This is a difference of about 1 billion tons of standard coal compared with about 6.2 billion tons of standard coal, which shows that the formulation and implementation of the strategy have a huge impact on energy demand.

(3) It can be seen from the scenario analysis plan that the optimization of energy structure, such as the development and utilization of hydropower, the development of new energy, and the vigorous development of nuclear energy and wind energy, has been optimistically conceived. However, due to the constraints of natural resource supply conditions and energy conversion technologies, it is very difficult to ensure an adequate supply of these clean energy sources. Therefore, combining the characteristics of China's energy structure, developing clean coal and coal utilization technologies, and improving energy utilization efficiency is a more effective guarantee for achieving the goal of a low-carbon economy.

(4) Seeking a breakthrough point for a win-win situation in energy conservation, emission reduction, and economic growth is one of the key issues in developing a low-carbon economy. From the energy consumption of various industries in the scenario forecast, it can be seen that the low energy-consuming service industry is not only a new bright spot for economic growth but also solves the employment of a large number of people and is an important area of China's development in the next few decades. On the contrary, the importance of industries, especially high energy-consuming industries, is gradually decreasing, and the focus is on improving energy-saving technologies; with the improvement of residents' living standards, the energy consumption in life continues to increase, and the increase in residents' low-carbon awareness will reduce this part of energy consumption. It plays a vital role.

5. Conclusion and Outlook

The development of low-carbon economy involves many fields such as policy, economy, environment, technology, and management. It is a complex systematic process. Due to the limitation of my own ability and research time, there are still many deficiencies, and many problems need to be further studied. The factors affecting China's low-carbon economy, especially the main influencing factors and the quantitative research on the development level of low-carbon economy deserves further research, which will help to predict energy consumption and carbon emissions more scientifically and accurately and provide more information for low-carbon economic development strategies for a reasonable decision-making basis. For example, the lack of low-carbon talents in the influencing factors, the poor low-carbon awareness of residents, and the relationship between the energy structure and energy efficiency in the scenario parameters. This paper also mainly adopts methods such as expert scoring and trend prediction and lacks the quantitative description of relationships. In order to facilitate analysis and calculation, this model ignores or incorporates some sources of carbon sources, such as carbon loss and some treatments lack rigor. The research angle mainly focuses on energy consumption, and there is insufficient research on other forms of carbon emissions, such as land use changes, which is the focus of the next stage of research. In this paper, the research on the development path of low-carbon economy mainly considers the relationship between energy consumption and total carbon emissions. It does not consider the cost of emission reduction nor does it consider other greenhouse gas emission reduction issues. This can be more helpful to scientifically and accurately predict economic development, the combination strategy between energy consumption and greenhouse gas emissions, and provide reasonable cost prediction and analysis for low-carbon economic development strategies.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

[1] T. H. Jones, L. J. Thompson, J. H. Lawton, and D. A BezemerBardgettBlackburn BruceCannonHallHartleyHowsonJonesKampichler KandelerRitchie, "Impacts of rising atmospheric carbon dioxide on model terrestrial ecosystems," *Science*, vol. 280, no. 5362, pp. 441–443, 1998.

[2] P. J. Diggle, K. Y. Liang, and S. L. Zeger, *Analysis of Longitudinal data[M]*, p. 253, Clarendon Press, Oxford, 1999.

[3] S. Levitus, J. I. Antonov, T. P. Boyer, and C. Stephens, "Warming of the world ocean," *Science*, vol. 287, no. 5461, pp. 2225–2229, 2000.

[4] H. N. Pollack, S. Huang, and P. Y. Shen, "Climate change record in subsurface temperatures: a global perspective," *Science*, vol. 282, no. 5387, pp. 279–281, 1998.

[5] J. Hansen, R. Ruedy, M. Sato, and T. ImhoffLawrenceEasterlingPetersonKarl, "A closer look at

United States and global surface temperature change," *Journal of Geophysical Research: Atmospheres*, vol. 106, no. D20, pp. 23947–23963, 2001.

[6] N. Stern, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge, 2007.

[7] D. Johnston, R. Lowe, and M. Bell, "An exploration of the technical feasibility of achieving CO2 emission reductions in excess of 60% within the UK housing stock by the year 2050," *Energy Policy*, vol. 33, no. 13, pp. 1643–1659, 2005.

[8] K. Shimada, Y. Tanaka, K. Gomi, and Y. Matsuoka, "Developing a long-term local society design methodology towards a low-carbon economy: an application to Shiga Prefecture in Japan," *Energy Policy*, vol. 35, no. 9, pp. 4688–4703, 2007.

[9] R. Kawase, Y. Matsuoka, and J. Fujino, "Decomposition analysis of CO2 emission in long-term climate stabilization scenarios," *Energy Policy*, vol. 34, no. 15, pp. 2113–2122, 2006.

[10] J. W. Warfield, "A Science of Generic Design," *Managing Complexity Through Systems Design*, Vol. 1, Intersystems Publications, , Salinas, CA, 1990.

[11] S. Jharkharia and R. Shankar, "IT-enablement of supply chains: understanding the barriers," *Journal of Enterprise Information Management*, vol. 18, no. 1, pp. 11–27, 2005.

[12] A. Mandal and S. G. Deshmukh, "Vendor selection using interpretive structural modelling (ISM)," *International Journal of Operations & Production Management*, vol. 14, no. 6, pp. 52–59, 1994.

[13] J. C. Duperrin and M. Godet, *Methode De Hierar Chization Des Elements D'um System*, pp. 45–51, Rapport Economique De CEA, Paris, 1973.

[14] V. Ravi and R. Shankar, "Analysis of interactions among the barriers of reverse logistics," *Technological Forecasting and Social Change*, vol. 72, no. 8, pp. 1011–1029, 2005.

[15] P. B. Stretesky and M. J. Lynch, "A cross-national study of the association between per capita carbon dioxide emissions and exports to the United States," *Social Science Research*, vol. 38, no. 1, pp. 239–250, 2009.

[16] S. GOmi, "A low-carbon scenario creation method for a local-sxale economy and its application in Kyoto city," *Energy Policy*, no. 31, pp. 325–345, 2009.

[17] U. Soytas and R. Sari, "consumption and GDP:Causality relationship in G-7 countries and emerging markets," *Energy Economics*, vol. 25, pp. 33–37, 2003.

[18] D. Diakoulaki and M. Mandaraka, "Decomposition analysis for assessing the progress in decoupling industrial growth from CO2 emissions in the EU manufacturing sector," *Energy Economics*, vol. 29, no. 4, pp. 636–664, 2007.