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Optimizing the Structure of Renewable Energy in Low-Carbon Ecosystem

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Abstract

At present, China has problems such as irrational energy structure and low energy utilization efficiency. Therefore, the optimization of energy structure is an inevitable trend of social and economic development. Based on the Analytic Hierarchy Process (AHP), the optimization methods for renewable energy structure of low-carbon ecosystems have been studied in depth through four criteria indicators: economy, technology, resources and environment. At the same time, the single-index quantification-multi-indicator integration evaluation method is used to comprehensively evaluate six renewable energy sources. According to the comprehensive index obtained, the renewable energy development priorities are reordered. The multi-objective planning model for optimizing the renewable energy structure in low-carbon ecosystems is constructed by maximizing the combination of six renewable energy comprehensive evaluation scores. The decision variables of the model are coal, oil, natural gas and six kinds of renewable energy. The costs of CO_2 emission and pollution control are minimized as the objective function of the model to maximize the overall benefits of the renewable energy portfolio. The experimental results show that the optimal ratio of hydropower, wind energy, solar energy, biomass energy, geothermal energy, and ocean energy is 38.5%, 35.7%, 16.8%, 3.0%, 3.0%, and 3.0%, respectively. The proposed optimization method shows that the proportion of optimal energy consumption predicted at the end of 2020 is 40.12% for coal, 21.42% for oil, 8.66% for natural gas, and 28.35% for renewable resources. This shows that coal is still the main source of energy in the future low-carbon ecosystem. The proportion of renewable energy represented by wind power, nuclear power, and hydropower in the overall energy structure has rapidly increased, gradually replacing traditional energy sources.

Keywords: low-carbon ecosystems, renewable energy, structural optimization, analytical hierarchy process, objective function

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INTRODUCTION

Under the background of the global exhaustion of oil and the deteriorating ecological environment, renewable energy has become the strategic choice for building the sustainable energy system and achieving the low-carbon economy (Zhao et al. 2017). As the major energy-consuming country, China is subject to factors such as resource endowment, consumption habits and technological dependence. Fossil energy such as coal, oil and natural gas plays the leading role in the primary energy consumption structure (Avera et al. 2015). The development of renewable energy is imminent.

At present, China's renewable energy technology has a low level of development and industrial development is uneven (Zhang et al. 2015), especially at the macro level. Considering the distribution of different resources, the initial investment and long-term benefits of development, the status quo and development trend of technology level hinder the efficient development and utilization of renewable energy and its structural optimization.

The development of renewable energy requires not only clear development goals and effective policy support, but also the comprehensive evaluation based on national conditions and renewable energy base (Bhattacharya et al. 2016), in order to form the well-defined and well-ordered policy evaluation. This not only provides the basis for the development of renewable energy development goals and differentiated support policies, but also provides the clear market orientation for enterprises. In this paper, the renewable resource structure in low-carbon ecosystems is optimized from both macro and micro directions. Comprehensive analysis of economic, technical, resource and environmental factors, the six renewable

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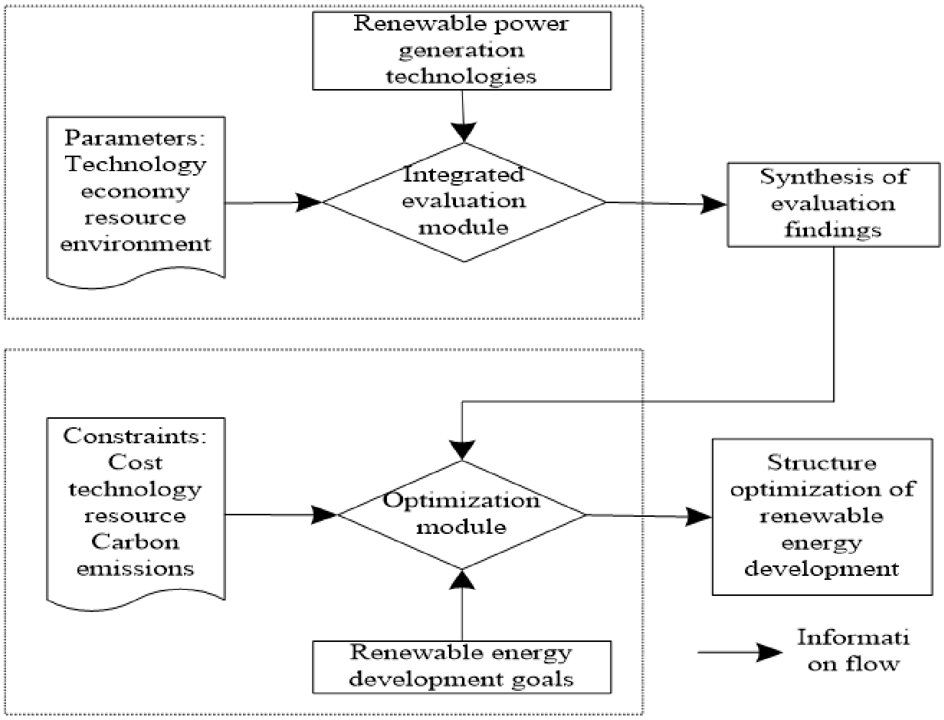

Fig. 1. Map of OMU Pond I and sampling station (Anonymous 1975)

energy comprehensive evaluation scores are maximized as the constraint to build the low carbon ecosystem renewable energy structure optimization model. The model's decision variables are coal, oil, natural gas, and six renewable energy sources. Minimize the external environmental cost of CO_2 emissions and environmental pollution control costs as the objective function of the model to optimize the renewable energy structure of low-carbon ecosystems.

MATERIALS AND METHODS

Optimized Technology Roadmap

In order to optimize the renewable energy of low-carbon ecosystems, this paper uses a bottom-up modeling method to construct a comprehensive evaluation and structural optimization model for renewable energy, namely the Renewable Energy Assessment and Optimization model. The REAO model integrates two modules: 1. The comprehensive evaluation module for renewable energy based on Analytic Hierarchy Process (AHP). Set core indicators from the four aspects of economy, technology, resources and environment, prioritize and comprehensively evaluate different renewable energy development. 2. Renewable energy development structure optimization modules. Based on the comprehensive evaluation results and the linear programming model, the comprehensive scores of various renewable energy combinations are maximized as the objective function. Taking into account constraints such as cost, technology, resources and carbon emissions, linear programming models are used to optimize the proportion of renewable energy development (Han et al. 2015). The entire model is shown in **Fig. 1**.

The model is built along the "renewable energy generation technology - utilization - structural planning" in low-carbon ecosystems. Based on the comprehensive evaluation module and optimization module, seek out the optimal allocation of renewable energy systems for low-carbon ecosystems in the future (Sun et al. 2015). Among them, the input of the comprehensive evaluation module is a series of technical, economic, resource and environmental parameters for renewable energy utilization. With the evaluation index system as the core, combined with the analytic hierarchy process, a comprehensive evaluation module is constructed. The input of the optimization module is part of the data of the comprehensive evaluation results and the constraints of the renewable energy development scenario (Zhang et al. 2017). The output is optimized for the development of renewable energy. The entire model is coupled from the micro-level of renewable energy generation technology, comprehensive evaluation of resource utilization to the entire process of macro-level development structure planning (Sharafi and Elmekkawy 2015).

Table 1. Generation cost of renewable energy in 2008

Renewable energy	Investment in fixed assets ($/ kW)	Electricity generation costs ($/kW · H)	External costs ($/kW · H)	total ($/kW · H)
wind energy source	8000	0.50	0.014	0.514
hydropower	8000	0.25	0.042	0.292
solar energy	120000	1.80	0.049	1.849
Biomass energy	—	0.80	0.015	0.815
Geothermal energy	—	0.40	0.046	0.446
Ocean energy	30000	3.00	0.012	3.012

Comprehensive Evaluation Method

Evaluation index design

The comprehensive evaluation of the development and utilization of renewable energy in low-carbon ecosystems is the systematic project involving many areas such as technology economy, resource environment and so on. In order to systematically solve this complex multi-objective decision-making problem layer, this paper based on the Analytic Hierarchy Process, the hierarchical structure is used to systematically link the complex relationships between the influencing factors. Under the constraints of the target layer, four criteria indicators such as economy, technology, resources and environment are set, and sub-criteria indicators such as installed capacity, power generation cost and technology maturity are set. The indicators are divided into two categories: quantitative indicators and qualitative indicators. Six renewable energy sources such as hydropower, wind energy, solar energy, biomass energy, geothermal energy and ocean energy are selected as evaluation targets. On the basis of comprehensive analysis of relevant research data and prediction results of domestic and foreign authoritative institutions and scholars, the indicators are assigned, and the development trends of key indicators such as cost and technology conversion efficiency are analyzed.

Indicator definition and analysis

(1) Economic indicators. One of the key factors in the development and use of renewable energy is economics, which includes two core indicators: power generation costs and installed capacity. The cost of power generation, as the quantitative indicator, is calculated using the full cost accounting method in this paper. External costs mainly refer to the environmental losses caused by renewable energy generation during its entire life cycle. Due to the lack of relevant data in China, the results of international research are referenced to determine it. The cost and total cost of each part are shown in **Table 1**. The installed capacity is the quantitative indicator that characterizes the development and utilization of renewable energy and affects its future development prospects.

(2) Technical indicators. Technical feasibility and limitations are important factors in determining the development of renewable energy. The main indicators include: energy processing conversion efficiency and technology maturity. Among them, energy processing conversion efficiency is the quantitative indicator to characterize the efficiency of renewable energy power generation technology application. Different renewable energy efficiency varies with equipment level and technical level. This paper comprehensively refers to China's energy science and technology development roadmap, National Development and Reform Commission research report, etc. The results of the study determined the energy processing conversion efficiency of six renewable energy power generation technologies by taking the average value. Technical maturity is the qualitative indicator that determines the current application of renewable energy power generation. The more mature the technology means easier to scale application. At present, hydropower technology is the most mature, followed by wind energy, solar energy and biomass energy, ocean energy and geothermal energy. The power generation technology is not mature enough and the application scale is small.

(3) Resource indicators include resource exploitability and distribution characteristics. The resource developable quantity is the quantitative indicator, which refers to the amount of resources that the renewable energy can be developed under the conditions of technical conditions. The fundamental determinant is the reserves of renewable energy resources. The distribution characteristics are qualitative indicators, which refer to the regional distribution characteristics of renewable energy. The good resource distribution should be close to the area of the power load center that is rich in renewable energy.

(4) Environmental indicators are mainly carbon emissions, which is a certain amount of indicators. Renewable energy itself has almost no carbon emissions, and replacing it with traditional energy sources can create a renewable resource structure in the low-carbon ecosystem. But in the entire life cycle of the

renewable energy industry, other links will lead to carbon emissions. Different renewable energy technologies have different impacts on ecology.

Indicator assignment

Quantitative indicators can be calculated directly from the interpretation of the indicators or from the literature and databases (Zheng et al. 2015), while qualitative indicators need to be obtained through expert consultation and literature review. According to the certain evaluation dimension, a variety of renewable energy sources are compared, and the score system of 1 to 10 points is adopted. The maximum relative condition is 10 points, and the relative condition is 1 point.

Data standardization

The power factor method is used to standardize the data so that it reflects the relative merits of an indicator in the series. For some indicators with higher expectations value, the following formula is standardized:

$$U_i(X_i) = \frac{X_i - X_{min}}{X_{max} - X_{min}} \times 40 + 60 \tag{1}$$

Where, $U_i(X_i)$ is the normalized data; X_i is the raw data value; $X_{\max}$ is the maximum value in the data series; $X_{\min}$ is the minimum value in the data series. For indicators with smaller expectations value, the following formula is standardized:

$$U_i(X_i) = \frac{X_{max} - X_i}{X_{max} - X_{min}} \times 40 + 60 \tag{2}$$

Output comprehensive evaluation results

This paper uses the evaluation method of single indicator quantification-multi-indicator integration to comprehensively evaluate six kinds of renewable energy comprehensive indexes. The basic ideas are as follows:

(1) Single indicator quantification includes quantitative indicators and qualitative indicators. The indicators belonging to the same criterion layer are coupled by linear weighting method, and finally the four criteria layer comprehensive evaluation index values are obtained: economic index, technical index, resource index and environmental index, as shown in formula (3):

$$U_i = \sum_{j=1}^{m} A_{ij} \times V_{ij} \tag{3}$$

Where, V_{ij} is the value of the jth indicator under the ith criterion level indicator; A_{ij} is the weight corresponding to the indicator; U_i is the i criterion level comprehensive evaluation index value.

(2) Multi-indicator integration: Using the linear weighting method, the four criteria layer comprehensive evaluation index is finally coupled into the renewable energy utilization comprehensive index (see formula (4)), and used as a benchmark for comprehensive evaluation and comparison of six renewable energy sources. The high composite index indicates that the renewable energy is easier to use than other alternatives under the evaluation criteria (Luo et al. 2016).

$$U = \sum_{i=1}^{m} \times A_i \times U_i \tag{4}$$

Where, U is the comprehensive index of renewable energy utilization; A_i is the corresponding weight of the ith criterion level indicators; U_i is the ith criterion level comprehensive evaluation index value.

(3) According to the size of the comprehensive index, the six renewable energy sources are sorted in order to obtain the expressions that maximize the evaluation of their scores.

$$maxh = 82.93 \times W_1 + 87.24 \times W_2 + 80.02 \times W_3 + 75.07 \times W_4 + 71.65 \times W_5 + 72.13 \times W_6 \tag{5}$$

This expression is used as a constraint for the subsequent renewable energy development structure optimization model.

(4) The use of renewable energy is in a period of rapid development. When comprehensively evaluating it, we should not only consider the status quo, but also focus on the future. Therefore, under the same set of indicator systems, the status quo and development trends are fully considered in this paper. The year 2008 is selected as the base year and 2020 as the year of the scenario, and the values of the relevant indicators are changed accordingly.

Optimization Modeling of Renewable Energy Development Structure

The 3E (Economy-Energy-Environment) concept seeks to maximize the overall benefits of the three. At present, the cost of renewable energy development and utilization is higher than that of fossil energy, but it has good resources and environmental benefits. At present, there are many defects in the structure of renewable energy, and fossil energy generates a large amount of CO_2 in the consumption process. The six kinds of renewable energy comprehensive evaluation score

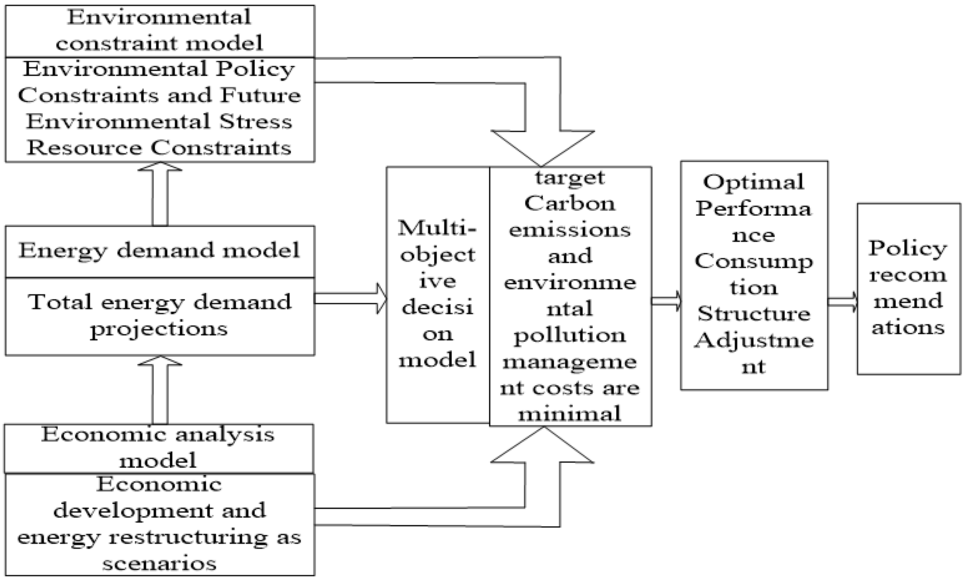

Fig. 2. Structure adjustment of renewable energy consumption and its optimal selection analysis model

combinations are maximized as constraints to build the multi-objective planning model for renewable energy structure optimization in low-carbon ecosystems. The optimization model for renewable energy structures is built with the goal of carbon emissions and environmental pollution control costs to maximize the overall benefits of the renewable energy portfolio (Song et al. 2015).

The model is a multi-objective decision problem, which is mainly divided into two types: one is that in the process of management decision-making, all targets can achieve the desired result to obtain the optimal solution, and such problems are also called multi-objective programming problems. The other is to measure all goals or criteria in the management decision process to arrive at all possible scenarios and, finally, to rank them according to the degree of satisfaction of the program (Yang et al. 2017). This type of problem is also known as a multi-objective optimization problem. The general step in solving the multi-objective decision problem is to first convert the multi-objective problem into the single-objective problem and then solve it (Mo et al. 2016) to get the optimal solution for the multi-objective problem. At the same time, the multi-objective problem is transformed into a single-objective decision-making problem, which is divided into two types: single-objective problem and multiple single-objective problems. The key to solving is the choice of method (Zhao et al. 2015).

The decision variables in the multi-objective programming model are the consumption of coal (x_1), petroleum (x_2), natural gas (x_3), and six renewable energy sources x_4. The objective function is to minimize the cost of CO_2 emissions and treatment costs. Then

$$\begin{gathered} minF(x) = (f_1(x), f_2(x)) \\ maxh = 82.93 \times W_1 + 87.24 \times W_2 + 80.02 \times W_3 \\ +75.07 \times W_4 + 71.65 \times W_5 + 72.13 \times W_6 \end{gathered} \tag{6}$$

Its weighted form is:

$$\begin{gathered} minF(x) = \lambda_1 f_1(x) + \lambda_2 f_2(x) \\ maxh = 82.93 \times W_1 + 87.24 \times W_2 + 80.02 \times W_3 \\ +75.07 \times W_4 + 71.65 \times W_5 + 72.13 \times W_6 \end{gathered} \tag{7}$$

Where, $f_1(x) = \sum_{i=1}^{4} \alpha_i x_i$, $f_2(x) = \sum_{i=1}^{4} \beta_i x_i$ (α_i is the external environmental cost of various energy sources, β_i is the pollution control cost for various energy sources)).

According to the “China Energy Medium- and Long-Term (2030, 2050) Development Strategy Study”, the future renewable energy consumption demand is forecasted.

The set constraints are:

The control range of CO2 emissions is$\sum_{i=1}^{4} \mu_i x_i \leq C_1$ $(C_1 = 61400)$;

Energy consumption is greater than the planned value , $\sum_{i=1}^{4} x_i \geq C_2$;

The future changes in the structure of renewable energy are:

Coal: $0.04 \leq x_1 / \sum_{i=1}^{4} x_i \leq 0.65$

Oil: $0.2 \leq x_2 / \sum_{i=1}^{4} x_i \leq 0.3$

Table 2. Emissions of various pollutants per ton of coal burned (in kg/t) and emissions per cubic metre of crude oil (in kg/m^3)

pollutant	Furnace			
		Power plant boiler	**Industrial boilers**	**Heating Furnace and Home Furnace**
Carbon monoxide(CO)	Coal / ton	0.23	1.36	22.7
	Crude oil per cubic metre	0.005	0.238	0.238
Hydrocarbons(CxHy)	Coal / ton	0.091	0.45	4.5
	Crude oil per cubic metre	0.381	0.238	0.357
Carbon oxide compound(NmOn)	Coal / ton	9.08	9.08	3.62
	Crude oil per cubic metre	12.47	8.57	8.57
smoke	Coal / ton	—	—	—
	Crude oil per cubic metre	1.2	Slag combustion 2.73 Steamed oil burning 1.80	0.952
Sulfur dioxide(SO_2)	Coal / ton	—	16.0S*	—
	Crude oil per cubic metre	—	20S*	—

Table 3. Emissions of pollutants per million cubic metre of fuel gas burned (in kg/mm^3)

pollutant	Furnace		
	A boiler	**Special boiler**	**Ordinary boilers**
Carbon monoxide(CO)	Ignore	630	630
Hydrocarbons(CxHy)	—	Ignore	—
Carbon oxide compound(NmOn)	6200	3400.46	1843.24
smoke	238.5	286.2	302
Sulfur dioxide(SO_2)	—	630	—

Table 4. Emission factors for each renewable energy pollutant (in kg/t standard coal)

A unit of coal.		One unit of oil.		A unit of natural gas.	
SO_2	smoke	SO_2	smoke	SO_2	smoke
20	13.1	7	1.05	0.47	0.21

Table 5. Costs of treatment of each renewable energy pollutant

Pollution control cost range	coal	oil	natural gas
Governance costs(yuan/ton standard coal)	76.89-164.89	23.49-56.39	1.63-3.84
Middle value(yuan/ton standard coal)	117.89	39.94	2.73

Natural gas: $0.08 \le x_3/\sum_{i=1}^{4} x_i \le 0.15$

Other renewable energy sources: $0.1 \le x_4/\sum_{i=1}^{4} x_i \le 0.3$;

Non-negative constraint, $x_i \ge 0$.

The assumptions for the multi-objective decision model are as follows:

(1) As the economy grows, China's renewable energy consumption also increases, while energy technology innovation and management levels increase slowly (Chen et al. 2016), which has little impact on energy consumption and can be ignored.

(2) The optimal conditions for renewable energy structure are cost minimization, that is, CO_2 emissions and treatment costs are minimal.

(3) Renewable energy produces little CO_2 during combustion and can be ignored.

According to the data published on the website of the National Bureau of Statistics, the amount of pollutants emitted by burning one unit of coal, oil and natural gas is shown in **Table 2** and **3**.

Since the pollutants emitted by renewable energy such as wind energy, water energy, solar energy and geothermal energy are very small during use, this paper sets these energy emission pollutants to zero. **Table 4** can be obtained by comprehensively sorting out various pollutants discharged from the above energy sources.

According to the China Energy Research Report - Regional Section, the minimum treatment cost per ton of sulfur dioxide is 3,300 Yuan, the highest treatment cost is 8,000 yean; the cost per ton of smoke is 373.33 Yuan. The cost of sulfur dioxide and soot is taken as the median value. According to the emission coefficient of each energy pollutant, the value range of the treatment cost of each energy pollution can be obtained as shown in **Table 5** (the value of the treatment cost, taking the middle value of the table interval).

The objective function is

$$f_1(x) = 117.89x_1 + 39.94x_2 + 2.73x_3 \quad (8)$$

Table 6. CO_2 emission factors for various renewable energy sources and external emission costs

	coal	oil	natural gas
CO_2 emission factor(t/tce)	2.408	2.151	1.622
External costs of CO_2 emissions(meta/tce)	791.63	707.14	533.23

Table 7. Structure of the index weight judgment matrix

index	economy	technology	resource	environment
economy	1/1	5/4	1/1	4/3
technology	4/5	1/1	4/5	5/4
resource	1/1	5/4	1/1	4/3
environment	3/4	4/5	3/4	1/1

Table 8. Calculation of the weight of indicators at all levels

Level 1 indicators	Level I indicator weights	Level II indicator	Weight of secondary indicators
economy	0.2813	Electricity generation costs (yuan/kW · H)	0.1688
		Installed capacity (10000 kW)	0.1125
technology	0.2344	Energy processing conversion efficiency (%)	0.1172
		Technical maturity	0.1172
resource	0.2813	Developable amount (billion kW)	0.1688
environment	3.2813	CO2 emissions (g/kW · H)	0.1015
		Other environmental impacts	0.1015

Table 9. 2008 comprehensive evaluation indicator assignments

Level 1 indicators	Level II indicator	hydropower	solar energy	Biomass.	geothermal	Ocean energy
economy	Electricity generation costs(yuan/kW · H)	0.292	1.849	0.815	0.412	3.046
	Installed capacity(10000 kW)	17500.000	20.000	315.000	2.480	2179.000
technology	Energy processing conversion efficiency (%)	80	14	20	15	70
	Technical maturity	9	7	8	3	4
resource	Developable	5.4	22.0	3.0	6.0	10.0
environment	amount(billion kW)	41	75	50	11	40
	Other environmental impacts	3	2	3	4	3

According to the results of domestic research, the carbon emission coefficients of various energy sources are: 0.656 t/tce for coal, 0.586 t/tce for petroleum, and 0.442 t/tce for natural gas. The amount of CO_2 released by the combustion of one ton of carbon in oxygen is 3.67 tons. In addition, according to relevant literature research, the external emission cost of CO_2 is about 20 US dollars / ton, which is converted into RMB 328 Yuan / ton. Therefore, the external emissions of various energy CO_2s are shown in **Table 6**.

The objective function is

$$f_2(x) = 791.63x_1 + 707.14x_2 + 533.23x_3 \quad (9)$$

RESULTS

Analysis of Comprehensive Evaluation Results

Weight assignment and standardization

The consulting expert group consists of experts from the energy research, energy, environment, economy, technology and management of Peking University, the Energy Research Institute of the National Development and Reform Commission, and the Chinese Academy of Sciences. The first-level indicator judgment matrix constructed based on the scoring results is shown in **Table 7**.

The weight vector calculated according to the AHP method is: A = (0.2813, 0.2344, 0.2813, and 0.2030). The consistency test results are: $\lambda max = 4.000$, $CR = 0.00 < 0.10$. The weights of the primary and secondary indicators are calculated in the same way. The results are shown in **Table 8**.

Base year evaluation

In 2008, the benchmark year, the value of each indicator is shown in **Table 9**. Data standardization and comprehensive evaluation results are shown in **Table 10**.

Analysis **Tables 9** and **10** show that when considering the four-dimensional factors of technology, economy, resources and environment, the six renewable energy utilization indexes are from high to low: hydropower, wind energy, solar energy, biomass, ocean energy and geothermal. This is basically consistent with the research results of the Chinese Academy of Sciences and the National Development and Reform Commission, but it is slightly different

Table 10. 2008 data standardization results and comprehensive evaluation results

index	hydropower	solar energy	Biomass.	geothermal	Ocean energy	hydropower
Electricity generation costs (yuan/kW · H)	96.78	100.00	77.39	92.40	98.26	60.00
Installed capacity (10000 kW)	62.77	100.00	60.04	60.71	60.00	64.98
Energy processing conversion efficiency (%)	72.73	100.00	60.00	63.64	60.61	93.94
Technical maturity	86.67	100.00	86.67	93.33	60.00	66.67
Developable	73.68	65.05	100.00	60.00	66.32	74.74
Amount (billion kW)	91.25	81.25	60.00	75.63	100.00	81.88
Other environmental impacts	100.00	73.33	86.67	73.33	60.00	73.33
Composite index of renewable energy use	82.93	87.24	80.02	75.07	71.65	72.13

Table 11. Assignment of indicators for scenario year I and scenario year II

Level 1 indicators	Level II indicator	hydropower	solar energy	Biomass.	geothermal	Ocean energy	hydropower
economy	Electricity generation costs (yuan/kW · H)	0.453	0.292	1.273	0.560	0.330	2.322
technology	Installed capacity (10000 kW)	55	90	40	40	30	80
	Energy processing conversion efficiency (%)	9	9	9	9	5	5
resource	Technical maturity	9.5	5.4	22.0	3.0	6.0	10.0
environment	Developable	25	41	75	50	11	40
	Amount (billion kW)	1	3	2	3	4	3

Table 12. Standardization of data for scenario years (2020) and synthesis of evaluation results

Level II indicator	hydropower	solar energy	Biomass.	geothermal	Ocean energy	hydropower
Electricity generation costs (yuan/kW · H)	96.83	100.00	60.14	63.91	60.00	63.91
Installed capacity (10000 kW)	73.27	100.00	60.14	63.91	60.00	63.91
Energy processing conversion efficiency (%)	76.67	100.00	66.67	66.67	60.00	93.33
Technical maturity	100.00	100.00	100.00	100.00	60.00	60.00
Developable	73.68	65.05	100.00	60.00	66.32	74.74
Amount (billion kW)	91.25	81.25	60.00	75.63	100.00	81.88
Electricity generation costs (yuan/kW · H)	100.00	73.33	86.67	73.33	60.00	73.33
Composite index of renewable energy use	85.39	87.24	82.93	75.46	71.75	71.16

from the international research results (the sustainable use of wind energy is higher than hydropower), because the gap between resource endowment and environmental impact is small. China's hydropower development time and cost and technology maturity advantages are much higher than other renewable energy sources.

Comprehensive evaluation scenario analysis

The comprehensive evaluation of renewable energy in low-carbon ecosystems should take into account the status quo and future development potential and trends. To this end, based on the 2008 comprehensive evaluation, this paper evaluates the future development trend of low-carbon ecosystem renewable energy in the scenario year (2015). Some indicators will change over time during the development trend evaluation process, including: power generation cost, installed capacity, energy processing conversion efficiency and technology maturity. The assignment of indicators in the scenario year is shown in **Table 11**, and the evaluation results are shown in **Table 12**.

According to the comprehensive evaluation scenario analysis, hydropower has been the renewable energy with the highest comprehensive utilization index due to the highest technology maturity and the largest scale of existing applications. However, from the perspective of development, the comprehensive utilization index of wind and solar energy is increasing and close to hydropower. This shows that with the improvement of technology maturity and the corresponding reduction of power generation costs, the advantages of these two renewable energy sources will gradually be reflected and the development prospects are good. For biomass energy, because the comprehensive evaluation of the

Table 13. 6 Optimization results of structural weights of renewable energy development

energy	hydropower	solar energy	Biomass.	geothermal	Ocean energy	hydropower
Weight (%)	35.7	38.5	16.8	3.0	3.0	3.0
Optimal total evaluation score	83.2					

relevant indicators in this paper focuses on renewable energy scale power generation technology, and this is only a part of biomass energy utilization, the advantages of biomass energy are not clearly reflected. Geothermal energy and ocean energy are subject to resource distribution and immature technology, and development will be relatively slow in the near future.

Analysis of Structural Optimization Results

The evaluation module gives the comprehensive evaluation based on a series of core indicators. However, in the actual policy formulation, it is necessary not only to optimize the development structure of various renewable energy sources under the premise of meeting the energy demand for sustainable economic development, but also to consider a series of objective constraints faced in the actual development of renewable energy. Apply this method to optimize the development scenarios of different renewable energy sources.

Specific constraints explained:

(1) The various renewable energy rights are significant or equal to zero.

(2) The sum of the weights of the six renewable energy sources is equal to one.

(3) Cost constraint: The development of renewable energy will inevitably bring about cost increase. The average future cost of renewable energy after optimization is less than or equal to the existing average cost.

(4) Technical constraints: The optimized development prospects of renewable energy are at a level above the average of six renewable energy combinations. Future renewable energy development is technically feasible. According to the comprehensive evaluation scenario analysis, the technical development prospects of wind energy, solar energy and biomass energy are the best. At the same time, the maturity of renewable energy technologies is above the current average of six renewable energy sources.

(5) Resource constraints: the developable amount of the optimized renewable energy portfolio is at a high level

(6) Carbon emission constraints: The future total renewable energy CO_2 emissions are below the current average emissions.

(7) In line with the idea of adapting to local conditions and comprehensive development, all kinds of renewable energy should be developed. According to the current status of renewable energy development, by 2020, the proportion of renewable energy will not be less than 3%.

Through this method, the multi-objective programming model for optimizing the structure of renewable energy in low-carbon ecosystems is constructed to solve linear programming. The best weights for the six renewable energy sources are shown in **Table 13**.

According to the Medium and Long-term Development Plan for Renewable Energy, China's renewable energy consumption will reach 15% by 2020, about 525 million tons of standard coal. According to the above table, the capacity of different renewable energy sources can be planned to guide the formulation of relevant national industrial policies.

The Relationship between Economic Growth and Energy Consumption

To perform regression analysis on GDP and energy consumption, data stability test (ADF test) must first be performed on the variable sequence. Only through the ADF test can they be correlated.

Stationary test

Whether there is a unit root in the test sequence of the ADF test, a non-stationary sequence if there is a unit root, and a stationary sequence if there is no unit root. If there is a unit root in the sequence, the regression is the pseudo-regression. Therefore, the time series can only be analyzed by the stationary test. This paper uses Eviews7.0 software to verify data stability and use the AIC criteria to determine the lag period. The ADF stationary test has the following conclusions: GDP, MT, QT, SY, TRQ (at a 5% confidence level) is the second-order single-round, and correlation analysis can be performed.

Regression analysis

After the ADF test, OLS regression analysis is performed on GDP and energy consumption. The R-square value of the obtained regression model is 0.993439, which indicates that the model has the good goodness of fit. The DW value is within a reasonable interval, there is no autocorrelation, and the F value is tested by the significance level.

The adjustment of the energy consumption structure should be carried out on the basis of ensuring economic growth. Assume that the annual economic growth rate is not less than 5%. In 2020, energy consumption needs to meet $-2804.277 + 0.921x_1 + 1.832x_2 + 5.045x_3 + 76.307x_4 \geq 87244.57$.

Solving the model

$$min(f_1(x), f_2(x))$$
$$f_1(x) = 117.89x_1 + 39.94x_2 + 2.73x_3$$
$$f_2(x) = 791.63x_1 + 707.14x_2 + 533.23x_3$$
$$s.t.\begin{cases} 2.408x_1 + 2.151x_2 + 1.622x_3 + 0x_4 \leq 61400 \\ -2804.277 + 0.921x_1 + 1.832x_2 + 5.045x_3 + 76.307x_4 \geq 87244.57 \\ 0.4 \leq x_1/\sum_{i=1}^{4} x_i \leq 0.65 \\ 0.2 \leq x_2/\sum_{i=1}^{4} x_i \leq 0.3 \\ 0.08 \leq x_3/\sum_{i=1}^{4} x_i \leq 0.15 \\ 0.1 \leq x_4/\sum_{i=1}^{4} x_i \leq 0.3 \\ x_i \geq 0 \end{cases} \tag{10}$$

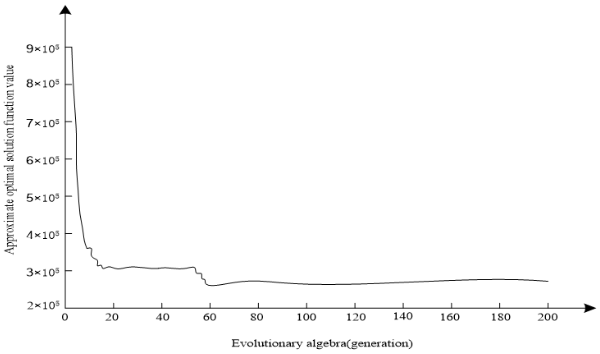

Fig. 3. Iterative curve of genetic algorithm

Calculation process and result analysis

After 200 iterations and processing, you can get:

X1=1571.8, X2=837.4, X3=384.9, X4=1115.6

That is, the proportion of optimal energy consumption predicted at the end of 2020 is: coal accounts for 40.12%, oil accounts for 21.42%, natural gas accounts for 8.66%, and renewable resources account for 28.35%.

It can be seen from the simulation results:

The proportion of coal in the total energy consumption has gradually declined. With the increasing global warming and pollution control costs of gas emissions from coal combustion, the country's restrictions on carbon emissions are increasingly strict, and the increase in coal consumption is relatively slow. However, other energy sources have high initial investment and low economic returns, making it difficult to compete with thermal power generation. For a long time to come, coal is still the main source of energy. The proportion of oil in the overall energy consumption has slightly decreased, and the proportion of natural gas has increased slightly, which is closely related to global oil price changes and pollution control costs. Oil plays a pivotal role in the overall energy structure. With the development of the economy, its dependence on foreign countries will become higher and higher in the future, and the issue of energy security is very worthy of attention.

DISCUSSION

The experimental results show that the optimal ratio of hydropower, wind energy, solar energy, biomass energy, geothermal energy, and ocean energy is 38.5 %, 35.7 %, 16.8 %, 3.0 %, 3.0 %, and 3.0 %, respectively. The proposed optimization method shows that the proportion of optimal energy consumption predicted at the end of 2020 is 40.12% for coal, 21.42% for oil, 8.66% for natural gas, and 28.35% for renewable resources.

The following suggestions are given.

(1) Although hydropower is the most mature renewable energy source, the unexploited resources and technological upgrading space limit the hydropower development to a larger scale, while wind energy and solar energy have broad development prospects. Therefore, starting from the long-term benefit analysis, it is should persist in vigorously developing wind energy, increase solar energy support, improve solar energy conversion efficiency, reverse the existing trade pattern of solar photovoltaic cells and equipment, clarify resource development goals, and create the broad domestic market to support related industries. .

(2) Biomass energy has obvious advantages in terms of cost and distribution. Unlike other renewable energy sources, which are mainly used for large-scale power generation, their use also includes biodiesel. Although the combined scores of geothermal energy and ocean energy are low, they do not affect their use in specific regions and conditions.

(3) In the renewable energy development strategy, structural optimization should be the focus. Under the premise of ensuring the safety of the province's energy

supply, resources within and outside the province should be rational used. With the sustainable development strategy as the guiding ideology, we will vigorously develop new energy industries.

CONCLUSIONS

Based on the Analytic Hierarchy Process (AHP), the optimization methods for renewable energy structure of low-carbon ecosystems have been studied in depth through four criteria indicators: economy, technology, resources and environment. At the same time, the single-index quantification-multi-indicator integration evaluation method is used to comprehensively evaluate six renewable energy sources. According to the comprehensive index obtained, the renewable energy development priorities are reordered. The multi-objective planning model for optimizing the renewable energy structure in low-carbon ecosystems is constructed by maximizing the combination of six renewable energy comprehensive evaluation scores. The decision variables of the model are coal, oil, natural gas and six kinds of renewable energy. The costs of CO_2 emission and pollution control are minimized as the objective function of the model to maximize the overall benefits of the renewable energy portfolio. The optimization results show that hydropower and wind energy are ranked high both now and in the future, while the future scenario evaluation scores of solar energy and biomass energy are higher than the baseline scenario, and the development potential is good. In the future low-carbon ecosystem, coal is still the main source of energy consumption, followed by renewable resources. Renewable energy represented by wind power, nuclear power and hydropower has rapidly increased its proportion in the entire energy structure and gradually replaced traditional energy sources. The diversification of renewable energy structure is the future development direction of renewable energy in low-carbon ecosystems.

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