Research on Multi-Objective Power Structure Optimization Based on NSGA-II under Carbon Trading

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Abstract

A series of problems caused by excessive carbon dioxide emissions are common challenges faced by all mankind. Electricity, one of the important secondary energy sources, will produce more carbon dioxide during its production process. Therefore, a reasonable and clean power supply structure is constructed to reduce carbon. Emissions are the key to the sustainable development of a country or region. This article first comprehensively considers the constraint conditions of electricity balance demand, and takes economic cost, carbon emissions and the proportion of clean power generation as the goals, and builds a multi-objective power structure optimization model that considers carbon trading. Secondly, taking Hebei Province as an example, the optimal solution set of the model is solved by the non-dominated sorting genetic algorithm (NSGA-II) of fast classification, and then the optimal solution is obtained by the TOPSIS method. The final results show that the power structure of Hebei Province from 2020 to 2030 will develop from a single power structure dominated by thermal power to a multiple power structure, and the proportion of clean energy power generation will continue to increase.

Keywords

Multi-objective optimization; carbon trading; power structure; NSGA-II; TOPSIS.

1. Introduction

Global warming is one of the biggest challenges facing mankind at present, and reducing carbon dioxide emissions is an important measure to mitigate climate warming. The power industry is one of the industries with the largest carbon dioxide emissions. Different types of power generation sources have different carbon emission effects. Therefore, the optimization of power supply structure is related to the sustainable and low-carbon development of a region or a country. To promote the low-carbon, clean and efficient development of China's power industry is not only the current research hotspot, but also our consensus. In order to achieve this goal, it is our primary task to establish a reasonable, clean and low-carbon power structure.

There have been many researches on power structure optimization at home and abroad. In the study of power structure model, researchers at home and abroad initially studied the problem of power structure planning considering new energy. Literature[1-3] considered the problem of power structure planning including wind farm and established a power structure model considering wind farm under the condition of analyzing the randomness and intermittency of wind farm. Literature[4] proposed a comprehensive optimization model of power structure based on comparative ranking with the objective of economy, and made an empirical analysis with Heilongjiang Province as an example. Literature[5] takes the lowest total generation cost of the power system as the objective function, fully considers the power load balance, electricity supply and demand balance and other realistic constraints, constructs the power structure optimization model of Jiangsu Province, and predicts the development path of power technology in Jiangsu Province. In Literature[6], a dual-objective optimization model combining economic benefits and environmental benefits was established by comprehensively considering resource endowment, power supply reliability, environmental impact and other influencing factors for renewable energy high-permeability areas, and C province was taken as an example for simulation and optimization calculation. Literature[7] establishes an energy system management model considering greenhouse gas emission reduction and coal consumption constraints to adjust regional power structure, analyzes the impact of different policy tools on power system performance, and takes Jiangsu Province as an example for an empirical study. Literature[8] takes thermal power generation, wind power generation and hydroelectric power generation into consideration, and combines environmental index to establish a multi-source electric energy planning scheme.

In the research of power structure intelligent algorithm, traditional methods mainly include fuzzy theory, expert meeting, neural network and other methods[9-13]. Literature[14] analyzes the power structure and energy saving and emission reduction in Inner Mongolia, establishes a multi-objective decision-making model for power structure optimization, and conducts an empirical study on this model by using genetic algorithm. Literature[15] establishes a power supply optimization model aiming at the lowest total cost, and uses a global or approximate global optimal solution method based on simulated annealing technology. In reference[16], Hagh M T et al. adopted heuristic algorithm based on group improvement to study the power supply optimization method. In literature[17], Zhang Junze and Ai Xin adopted the improved algorithm based on particle swarm optimization to optimize the problem of distributed power supply. In literature[18], Ma Xiyuan et al. studied the microgrid problem with the combination of wind, light and storage by using an improved bacterial foraging algorithm. In literature[19-21], carbon emission was introduced into the power structure optimization model as a constraint condition or objective function, and a multi-objective optimization model considering carbon emission reduction effect was established. Ant colony algorithm and particle swarm optimization algorithm were applied to simulate the model.

In the previous studies, the power structure optimization models constructed are all single objective or dual objective, rather than multi-objective power structure optimization models with three objective functions or more. In addition, in the existing studies, the methods used are ordinary optimization methods or evolutionary algorithms, and the accuracy and rapidity need to be improved.

Therefore, in the case of carbon trading, this study established a power structure optimization model with economic cost, carbon emissions and the proportion of clean power source as targets. The model comprehensively considered the constraints of electricity demand, the maximum installed capacity of renewable energy, the reserve rate of power system and other constraints. In addition, taking Hebei Province as an example, the optimization results of power structure in 2020, 2025 and 2030 in Hebei Province were obtained by using the Non-dominated Sorted Genetic algorithm-II (NSGA-II) and the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). Finally, the results are analyzed. In this study, the power structure optimization model established on the basis of considering carbon trading is more accurate and specific, and the model solution using NSGA-II algorithm and TOPSIS method is more accurate and fast.

2. Multi-objective optimization model of power supply structure under carbon trading

Carbon trading is a market mechanism used to promote global greenhouse gas emission reduction and reduce global carbon dioxide emissions. The construction of the multi-objective optimization model of power structure based on carbon trading needs to consider many factors.

In order to improve the practicability of the model, the following assumptions are proposed for the model:

(1) Only the carbon emissions from the power generation process are considered. Solar power generation, wind power generation and other clean energy power generation will not produce carbon emissions in the process of power generation, but will produce carbon emissions in the preliminary construction and preparation process. For the convenience of calculation, the carbon emission of its preliminary work is not considered.

(2) Coal is the only fuel for thermal power generating units. The influence of fuel and gas generating units is not considered, and only the power generation and carbon emissions of coal-fired generating units are considered.

(3) The climbing characteristics of the unit are not considered. For example, when the thermal power unit starts cold, it generally takes 6-10 hours to reach full load operation. If this factor is taken into account, the uncertainty of the model will be greatly increased. Therefore, the model constructed in this study does not consider the unit's climbing characteristics.

2.1. The objective function

(1) The minimum total economic cost: The total economic cost is divided into power generation cost and carbon trading cost.

The generation cost is equal to the product of the unit generation cost of each type of power source and the generation amount, as shown in formula (2-1) :

$$\min C_t = \sum_{i=1}^{m} \mu_{i,t} \times x_{i,t} \qquad \text{Formula (2-1)}$$

Where, C_t ——Total power generation cost in year t, unit: 100 million yuan;

$\mu_{i,t}$ ——Unit power generation cost of the i-th power source in year t, unit: yuan$/kW \cdot h$;

$x_{i,t}$ ——The quantity of orders issued for the i-th power supply in year t, unit: 100 million $kW \cdot h$.

The cost of carbon trading needs to consider the allocation of carbon emissions, so the cost of carbon trading is: the total amount of carbon dioxide produced by the i-th power source in year t minus the corresponding allocation of carbon dioxide, and the remaining part is multiplied by the carbon trading price, as shown in formula (2-2) :

$$\min C_t^{CO_2} = \sum_{i=1}^{m} p_{CO_2} \left(\omega_{i,t} - \eta\right) \times x_{i,t} \qquad \text{Formula (2-2)}$$

Where, $C_t^{CO_2}$ ——The total cost of carbon trading in year t, unit: yuan;

p_{CO_2} ——Carbon trading price, unit: yuan;

$\omega_{i,t}$ ——The carbon emission intensity of the i-th power source in year t, unit: $t / kW \cdot h$;

η ——Allocation of carbon emissions per unit of electricity, unit: $t / MW \cdot h$;

$x_{i,t}$ ——The quantity of orders issued for the i-th power source in year t, unit: 100 million $kW \cdot h$.

The total economic cost is the smallest: the power generation cost and the carbon transaction cost are the smallest sum. As shown in formula (2-3):

$$\min f_1(x) = \min\left(C_t + C_t^{CO_2}\right) = \sum_{i=1}^{m}\left[\mu_{i,t} \times x_{i,t} + p_{CO_2}\left(\omega_{i,t} - \eta\right) \times x_{i,t}\right] \qquad \text{Formula (2-3)}$$

(2) Minimum carbon emissions: carbon emissions are equal to the product of the carbon emission intensity of various types of power sources and power generation, as shown in formula (2-4):

$$\min f_2(x)=\sum_{i=1}^{m}\omega_{i,t}\times x_{i,t} \qquad \text{Formula (2-4)}$$

Where, $\omega_{i,t}$ ——The carbon emission intensity of the i -th power source in year t , unit: $t/kW\cdot h$;

$x_{i,t}$ ——The quantity of orders issued for the i -th power source in year t, unit: 100 million $kW\cdot h$.

(3) The largest proportion of clean power sources: refers to the highest proportion of clean energy power generation such as hydropower, wind power, and solar power in the power structure, as shown in the formula (2-5):

$$\max f_3(x)=\frac{\sum_{i=2}^{m}x_{i,t}}{\sum_{i=1}^{m}x_{i,t}} \qquad \text{Formula (2-5)}$$

Where, $x_{i,t}$ ——The quantity of orders issued for the i -th power source in year t, unit: 100 million $kW\cdot h$.

2.2. The constraint

(1) Electricity demand constraints

Various types of power sources will be affected by the operating status of the equipment and natural resource conditions during operation, resulting in the inability to maintain the maximum output. However, the total power generation of various power sources must meet the demand for electricity in the whole society, so the annual power generation of various power sources needs to meet the formula (2-6):

$$\sum_{i=1}^{m}x_{i,t}\times\left(1-\sigma_{i,t}\right)\geq d_t \qquad \text{Formula (2-6)}$$

Where, $x_{i,t}$ ——The quantity of orders issued for the i -th power source in year t, unit: 100 million $kW\cdot h$;

$\sigma_{i,t}$ ——Comprehensive plant power consumption rate of the i -th power source in year t, unit: $\%$;

d_t ——The predicted value of electricity demand in the whole society in year t, unit: 100 million $kW\cdot h$.

(2) System reserve rate constraint

Each power system must be equipped with a certain reserve capacity to prepare for equipment maintenance or emergency accidents. Power reserve capacity mainly includes accident reserve capacity, maintenance reserve capacity and load reserve capacity. In order to ensure the reliability of the power system, the total available installed capacity of the system in the first year should be greater than or equal to the sum of the maximum load and the reserve capacity, as shown in the formula (2-7):

$$\sum_{i=1}^{m}\frac{x_{i,t}\times\left(1-\sigma_{i,t}\right)}{h_{i,t}}\geq(1+r)L_{\max t}^{d} \qquad \text{Formula (2-7)}$$

Where, $x_{i,t}$ ——The quantity of orders issued for the i-th power source in year t, unit: 100 million $kW\cdot h$;

$\sigma_{i,t}$ ——Comprehensive plant power consumption rate of the i-th power source in year t, unit: %;

$h_{i,t}$ ——The annual power generation utilization hours of the i-th power source in year t, unit: h;

r ——Power reserve rate, unit: %;

$L_{\max t}^{d}$ ——Maximum electrical load in year t, unit: 100 million kW.

(3) Constraints on the maximum installed capacity of renewable energy

The annual extraction of various types of renewable energy is limited by natural resources. During the planning period, the development of renewable energy must be carried out in accordance with the relevant national policies, such as formula (2-8):

$$\frac{x_{i,t}}{h_{i,t}} \le G_{\max,i,t} \qquad \text{Formula (2-8)}$$

Where, $x_{i,t}$ ——The quantity of orders issued for the i-th power source in year t, unit: 100 million $kW\cdot h$;

$h_{i,t}$ ——The annual power generation utilization hours of the i-th power source in year t, unit: h;

$G_{\max,i,t}$ ——The maximum installed capacity of the i-th power source in year t, unit: Ten thousand kW, among them $i=2,3,4$.

(4) Energy security constraints

The optimization of the power supply structure must be based on safety, and the power supply structure based on fossil energy will not be easily changed for a period of time. Therefore, the proportion of thermal power generation is greater than 40%, such as formula (2-9):

$$x_{h,t} \ge 40\% \times x_t \qquad \text{Formula (2-9)}$$

Where, $x_{h,t}$ ——Thermal power generation capacity in year t, unit: 100 million $kW\cdot h$;

x_t ——Total power generation in year t, unit: 100 million $kW\cdot h$.

(5) Non-negative constraints

$$x_{i,t} \ge 0 \qquad \text{Formula (2-10)}$$

Where, $x_{i,t}$ ——The quantity of orders issued for the i-th power source in year t, unit: 100 million $kW\cdot h$.

3. An optimization method

This paper established a power structure based on multi-objective optimization model, the NSGA - Ⅱ algorithm. In general, the optimal solution for multi-objective problems is a solution set rather than a single solution, namely the Pareto optimal solution or the Pareto frontier. In this case, it is difficult to select the best solution according to the obtained Pareto Front due to the high precision and long processing time required. In order to find an optimal solution from the obtained solution set, TOPSIS, a multi-criteria decision method, will be used[22].

3.1. The NSGA-II algorithm

The NSGA-II algorithm with elite reserved strategy of rapid and dominate multi-objective optimization algorithm, is a kind of multi-objective optimization algorithm based on the Pareto optimal solution. The basic idea of the algorithm is as follows: firstly, the initial population of size N is randomly generated, and then the first generation of offspring population is obtained through three basic operations of genetic algorithm, namely selection, crossover and mutation, after non-dominated sorting. Secondly, starting from the second generation, the parent population was merged with the offspring population to conduct a fast non-dominant ranking. At the same time, the crowding degree of individuals in each non-dominant layer was calculated. According to the non-dominant relationship and the crowding degree of individuals, appropriate individuals were selected to form new parent population. Finally, a new progeny population is generated by the basic operation of genetic algorithm. And so on until the conditions for the termination of the program are met[23].

3.2. TOPSIS method

TOPSIS method has outstanding performance in evaluating alternatives and criteria, and can find the best solution of decision problems by calculating the geometric distance between each solution and the positive ideal solution (PIS) and negative ideal solution (NIS). Compared with other solutions, the distance between the optimal solution and Pis is the shortest and the distance between the optimal solution and NIS is the longest[24]. The calculation process of TOPSIS method is as follows:

Step 1: Construct an evaluation matrix containing the m optimized solutions as alternatives and n evaluation criteria $A=(a_{ij})_{m\times n}$,the criteria here are composed of three optimization goals: total economic cost, carbon emissions, and the proportion of clean energy power generation.

Step 2: Normalize matrix A , and generate formula (2-11) normalized matrix $\tilde{R}=[\tilde{r}_{ij}]$.

$$\tilde{\mathrm{r}}_{ij}=\frac{a_{ij}}{\sqrt{\sum a_{ij}^{2}}} \qquad \text{Formula (2-11)}$$

Step 3: Use standard weights $\tilde{Z}=[\tilde{Z}_{ij}]$ and $\tilde{z}_{ij}=\tilde{r}_{ij}(\bullet)\tilde{w}_{j}$ to construct a weighted normalized evaluation matrix.

Step 4: Determine PIS and NIS according to the maximum and minimum values of $\tilde{Z}$ in formula (2-12).

$$Q^{+}=\left\{\tilde{z}_{1}^{+},\tilde{z}_{2}^{+},\cdots,\tilde{z}_{n}^{+}\right\},Q^{-}=\left\{\tilde{z}_{1}^{-},\tilde{z}_{2}^{-},\cdots,\tilde{z}_{n}^{-}\right\} \qquad \text{Formula (2-12)}$$

Where, $Q_{j}^{+}=\min_{i}(\tilde{z}_{ij})$, $Q_{j}^{-}=\max_{i}(\tilde{z}_{ij})$.

Step 5: Use formula (2-13) to calculate the alternative distance from PIS to NIS.

$$d_{i}^{+}=[\sum_{j=1}^{n}(\tilde{z}_{ij},z_{j}^{+})^{2}]^{1/2},d_{i}^{-}=[\sum_{j=1}^{n}(\tilde{z}_{ij},z_{j}^{-})^{2}]^{1/2} \qquad \text{Formula (2-13)}$$

Step 6: Calculate the closeness coefficient using formula (2-14), and rank the alternatives.

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \qquad \text{Formula (2-14)}$$

In the above formula, $\tilde{r}_{ij}$ and $\tilde{z}_{ij}$ are the normalized value and weighted normalized value of the i-th criterion alternative, respectively, $\tilde{w}_j$ represents the standard weight, when NIS is represented by Q_j^-, PIS is represented by Q_j^+, and CC_i is the closeness coefficient, if the alternative is closer to PIS and farther from NIS, it is close to 1.

3.3. Optimization framework

Using the NSGA-II algorithm and TOPSIS optimization framework consists of three main steps: initialize the constructed model and the related parameters, the NSGA-II algorithm are used to get the optimal solution set (Pareto Front), using TOPSIS method to choose the only optimal solutions, optimization of the process is shown in figure 1.

4. The example analysis

4.1. Basic data

(1) Electricity Demand of Hebei Province

Using the gray-scale prediction model, the predicted values of power demand in Hebei Province in 2020, 2025, and 2030 are 3440.08 100 million $kW \cdot h$, 363.15 100 million $kW \cdot h$, and 100 million $kW \cdot h$.

(2) Unit cost of power generation

According to the on-grid benchmark electricity price and the data in literature[25][26], this study adopts 0.36 yuan $/kW \cdot h$, 0.38 yuan $/kW \cdot h$, 0.80 yuan $/kW \cdot h$ and 0.33 yuan $/kW \cdot h$ as the unit power generation cost of thermal power, wind power, solar power and hydropower in Hebei Province in 2020 respectively.

Due to the limited energy resources, with the development of society, the cost of coal-fired thermal power generation will rise. According to the literature, in this study, the cost of thermal power generation in 2025 and 2030 is set as 0.378 yuan $/kW \cdot h$ and 0.396 yuan $/kW \cdot h$.

At the same time, with the development of science and technology, wind power, solar power generation and hydropower investment and maintenance cost will be decrease.In this study, 0.361 yuan $/kW \cdot h$ and 0.342 yuan $/kW \cdot h$ are used as the cost of wind power generation in 2025 and 2030, 0.76 yuan $/kW \cdot h$ and 0.72 yuan $/kW \cdot h$ are used as the power generation cost of solar power in 2025 and 2030, and 0.31 yuan $/kW \cdot h$ and 0.30 yuan $/kW \cdot h$ are used as the power generation cost of solar hydropower in 2025 and 2030.

(3) Carbon emission intensity

According to the carbon emission coefficient of 0.67 per unit standard coal and the average power supply coal consumption of thermal power units, the carbon dioxide emission generated by coal burning to obtain 1 kWh of power is calculated to be about 0.76 kg, and this index will not change significantly in a short period of time.

(4) Allocation quota for unit electricity emission

According to the literature survey results, the average value of the marginal emission factor BM of capacity and the marginal emission factor OM of electricity is generally adopted as the allocation limit of unit electricity emission[27]. Through the grey prediction, the allocation limit of unit electricity emission in Hebei Province in 2020, 2025 and 2030 is 0.73 $t/MW \cdot h$, 0.68 $t/MW \cdot h$ and 0.64 $t/MW \cdot h$.

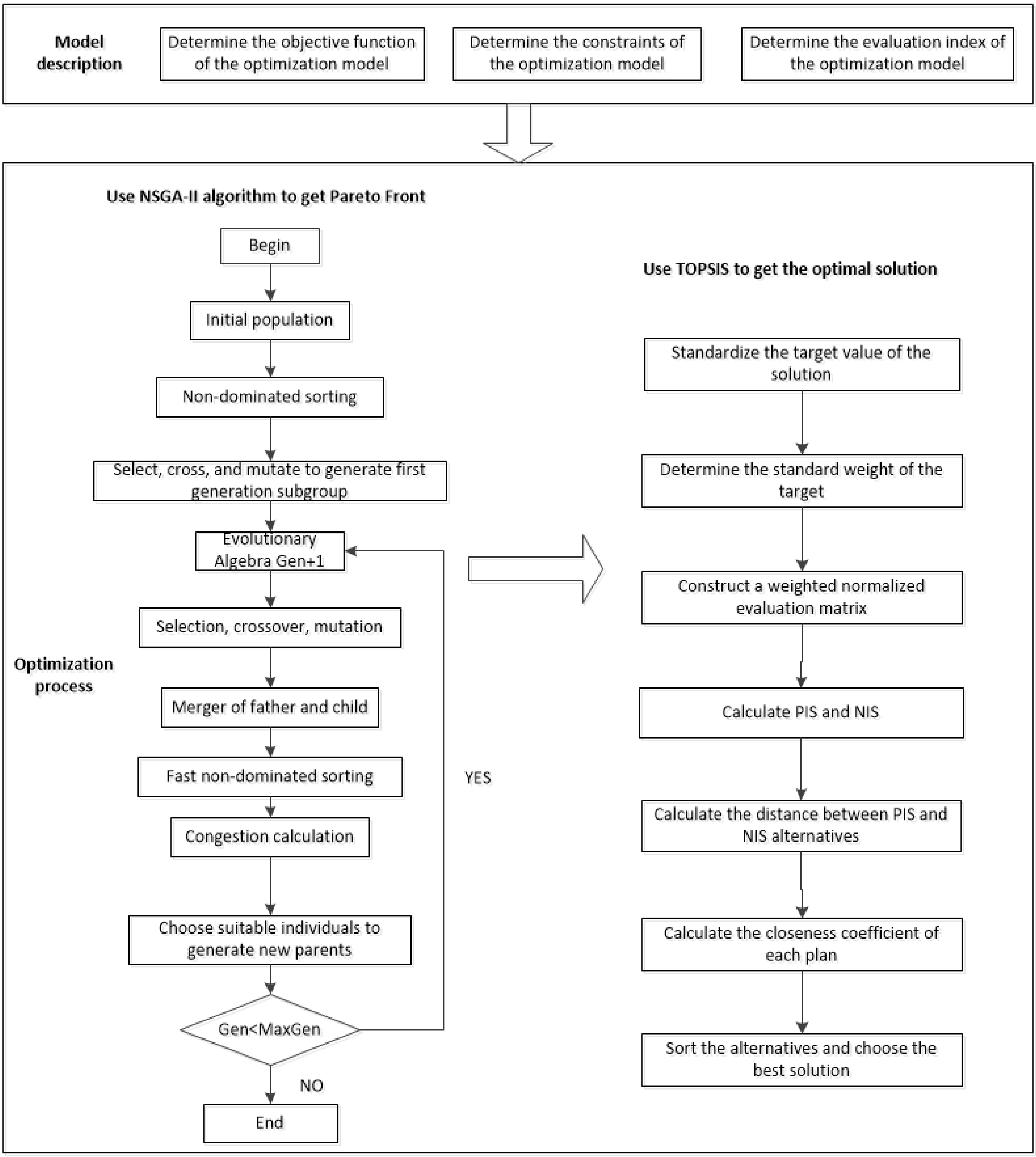

Figure 1: Optimization framework

(5) Carbon trading price

The carbon trading price keeps changing all the time. According to the historical trading price[27], 30 yuan/t , 35 yuan/t and 40 yuan/t are selected as the carbon trading price for 2020, 2025 and 2030 in Hebei Province.

(6) Power consumption rate

In recent years, the plant power consumption rate of various power sources in Hebei Province has not changed significantly, so the average value of recent years is taken as the basis for model calculation, and the plant power consumption rate of thermal power, wind power, solar power and hydropower is 7.07%, 2.16%, 1.30% and 1.00% respectively.

(7) The number of power generation hours per year

In recent years, the annual power generation utilization hours of Hebei Province have not changed significantly, so the average value of recent years is taken as the basis for model calculation. The power generation utilization hours of thermal power, wind power, solar power and hydropower are 5351 hours, 2097 hours, 1289 hours and 705 hours respectively.

(8) Maximum power load

The annual maximum electricity load of Hebei Province has an upward trend in recent years. The grey prediction model can be used to predict the maximum electricity load of Hebei Province in 2020, 2025 and 2030 as 76 million kilowatts, 97 million kilowatts and 116 million kilowatts[28].

(9) Power reserve ratio

In general, the power reserve rate is 12 to 25 percent. According to the actual situation of Hebei Province, this paper selects 12% as the power reserve rate of Hebei Province.

(10) Maximum installed capacity of renewable energy

According to the 13th Five-Year Renewable Energy Plan of Hebei Province[29][30], by 2020, the installed capacity of wind power, solar power and hydropower in Hebei Province is expected to reach 20.8 million kilowatts, 15 million kilowatts and 3.64 million kilowatts. Then using the same growth rate, we can get the approximate situation in 2025, 22.5 and 5.1 GW respectively, and in 2030, 51 GW, 33 GW and 7.6 GW respectively.

4.2. Results analysis

According to the power structure multi-objective optimization model mentioned above and the basic data of Hebei Province, NSGA-II algorithm and TOPSIS method were used to solve the power structure multi-objective optimization model of Hebei Province in 2020, 2025 and 2030, and the solution results were analyzed.

Firstly, the optimal solution set of the multi-objective power structure optimization model in Hebei Province in 2020 is solved. Under the parameters set in this study, there are a total of 10 initial optimal solutions in the Pareto front, as shown in Table 1.

Table 1: 2020 Hebei Province Power Structure Optimization Results

Numble	Thermal power genera -tion $/kW\cdot h$	Wind power genera -tion $/kW\cdot h$	Solar power genera -tion $/kW\cdot h$	Hydro power genera -tion $/kW\cdot h$	Economic cost /100 million yuan	Carbon emission/100 million t	Proportion of clean power generation /%
1	3187.9	367.6	130.5	34.5	4272.3	2422.8	14.32%
2	3220.7	363.2	125.7	33.8	4307.9	2447.8	13.96%
3	3196.2	359.5	123.7	31	4273	2429.1	13.86%
4	3235.7	340	137.3	34	4327.3	2459.2	13.65%
5	3164	359.6	131	32.8	4238.9	2404.6	14.19%
6	3204.5	356.7	129.2	30.2	4286.5	2435.4	13.87%
7	3233.3	362.6	138.7	31.7	4333.2	2457.3	14.15%
8	3178.1	341.2	128.1	30.9	4246.7	2415.4	13.60%
9	3230.9	363.8	135.6	30.6	4327.8	2455.5	14.09%
10	3174.3	360.2	120.9	34.7	4244.8	2412.5	13.98%

After NSGA-II algorithm, 10 solutions were obtained as the evaluation matrix of TOPSIS method for further processing. The three targets were taken as the evaluation criteria, and the weight of the criteria was [0.3,0.3,0.4]. According to the calculation steps of TOPSIS, the optimal solution of power structure optimization in Hebei Province in 2020 was selected. Similarly, the optimization results of power supply structure in Hebei Province in 2025 and 2030 are solved, as shown in Table 2.

Table 2: Ptimization results of power supply structure in Hebei Province

Years	Thermal power genera -tion /$kW\cdot h$	Wind power genera -tion /$kW\cdot h$	Solar power genera -tion /$kW\cdot h$	Hydro power genera -tion /$kW\cdot h$	Economic cost /100 million yuan	Carbon emission/100 million t	Proportion of clean power generation /%
2020	3164	359.6	131	32.8	4238.9	2404.6	14.19%
2025	3242.0	474.0	248.0	85.0	10689.0	2464.0	19.93%
2030	3321	609	348	130	17754	2524	24.66%

In summary, the optimization results of power structure in Hebei Province in 2020, 2025 and 2030 are shown in Table 3, Figure 2 and Figure 3.

Table 3: Optimization results of power supply structure in Hebei Province

Years	Proportion of thermal power generation/ %	Proportion of wind power generation/ %	Proportion of solar power generation/ %	Proportion of hydropower generation/ %	Total power generation /100 million $kW\cdot h$
2020	85.81%	9.75%	3.55%	0.89%	3687.4
2025	80.07%	11.71%	6.12%	2.10%	4049.0
2030	75.34%	13.82%	7.89%	2.95%	4408

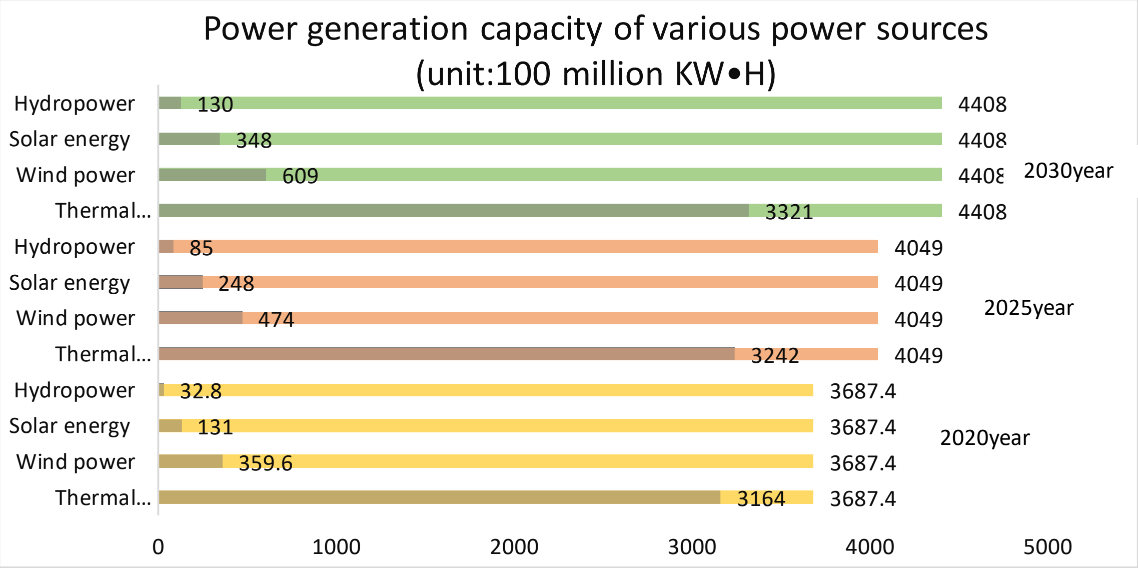

Figure 2: Various types of power generationk

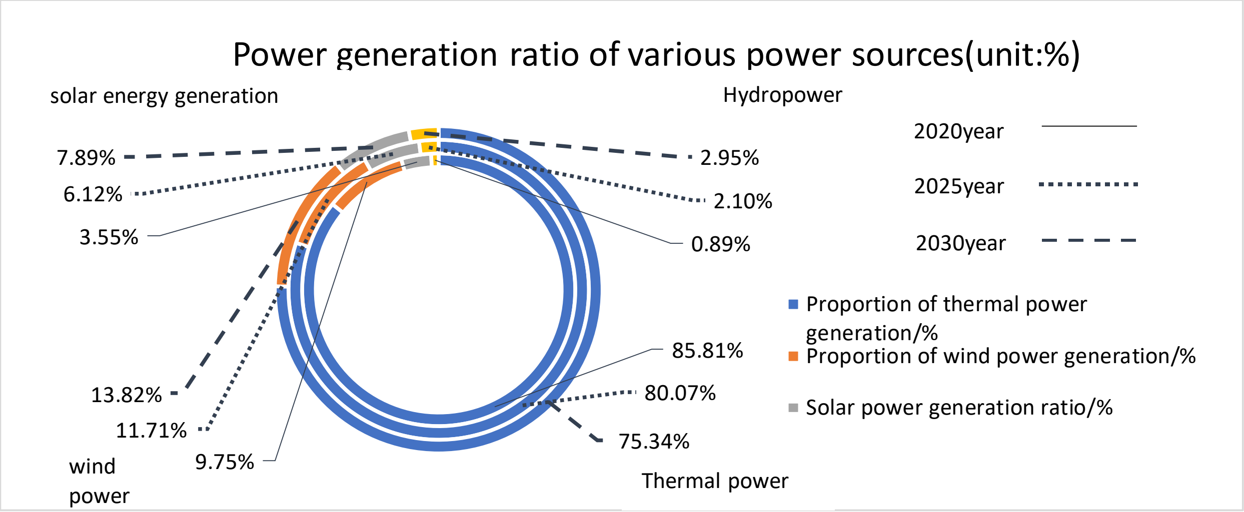

Figure 3: Power generation ratio of various power sourc

From the perspective of the proportion of various types of power generation, the proportion of thermal power generation in Hebei Province is gradually decreasing, while the proportion of clean energy generation such as wind power, solar power and hydropower is increasing year by year. Thermal power increased from 85.81 percent in 2020 to 75.34 percent in 2030, wind power from 9.75 percent to 13.82 percent in 2030, solar power from 3.55 percent to 7.89 percent in 2030, and hydropower from 0.89 percent to 2.95 percent in 2030.

From a numerical point of view, although the proportion of thermal power generation continues to decline, the value of its power generation is still increasing, resulting in an increase in Hebei's carbon emissions from 2020 to 2030. On the other hand, the power generation and proportion of clean energy such as wind power, solar power and hydropower are on the rise, making the power structure of Hebei Province cleaner, low carbon and more efficient in the future.

In general, under the action of carbon trading mechanism and carbon emission reduction target, the power structure dominated by thermal power in Hebei Province will gradually improve, and transition to a diversified structure of thermal power, wind power, solar power, hydropower and other power generation energy.

5. Conclusion

With the goal of sustainable and low-carbon development, the power mix of the future will definitely focus on increasing the proportion of clean energy generation. In this study, under the background of carbon trading, a multi-objective optimization model of power structure in Hebei Province was constructed, and NSGA-II algorithm and TOPSIS method were used to calculate the optimization results of power structure in Hebei Province in 2020, 2025 and 2030. The results also show that the power structure of Hebei Province in the future will be composed of thermal power, wind power, solar power and hydropower, and the proportion of clean energy power generation will continue to increase. Through the example analysis, it shows that the multi-objective optimization model of power structure established in this study has a certain practical significance, and can also provide some reference for the optimization of power structure in other areas. One of the innovations of this study is the establishment of a multi-objective power structure optimization model with three objective functions, which makes the model more specific and accurate. Another innovation is to use NSGA-II algorithm and TOPSIS method to solve the model, which improves the accuracy and rapidity of the solution. However, the multi-objective optimization model of power structure in this paper also has some defects. For example, in order to consider some uncertain factors, it can be further improved in the subsequent research.

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