Multi-objective Optimization Method of Manufacturing Carbon Emissions Based on Firefly Algorithm

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Abstract. The carbon emission optimization goal is easy to achieve local optima, which affects the optimization effect. Therefore, a multi-objective optimization method for manufacturing carbon emissions based on the firefly algorithm was designed. On the basis of the Firefly algorithm, a multi-objective optimization model for carbon emissions in the manufacturing industry was constructed, enabling other goals to achieve global optimization, fully considering the changes in energy structure, energy intensity, and economic changes, and achieving the carbon emission reduction task of the manufacturing industry. The comparative experimental results show that this method has good carbon emission optimization effect and can be applied in practical life.

Keywords: Firefly algorithm; Manufacturing industry; Carbon emissions; Multi-objective; Optimization method;

1 Introduction

The conventional multi-objective optimization method of carbon emission in manufacturing industry combines the advantages of genetic algorithm, and optimizes the problems such as insufficient energy production, limited development of new energy and serious external dependence of energy. Although it achieves the goal of carbon emission reduction, it also delays the development progress of new energy industry. Under the background of dual carbon, the energy structure changes obviously, the energy intensity fluctuates greatly, and the economic growth rate is slow, which increases the difficulty of multi-objective optimization of carbon emissions. At present, scholars have conducted relevant research. Reference [1] used Granger causality and appropriate panel data regression models to explore the relationship between economic growth and carbon dioxide emissions in developing countries in the Asian region, taking into account factors such as urbanization, commodity trade, foreign direct investment, and renewable energy consumption. Due to limitations in the collection and reporting of statistical data, there may be missing or incomplete data, which in turn affects the accuracy and reliability of the model. The literature [2] evaluates the energy and effective energy price of jet kerosene fuel required by aircraft used in Türkiye's air transport field, taking into account the carbon emission equivalence of the fuel. By analyzing 12 months of

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data, the effective energy price of fuel and the carbon emissions equivalent based on the effective energy price were calculated. But this method has some limitations. Firefly algorithm can choose the optimal structure according to nature, and purify the targets with different structures, and imitate the flash characteristics of fireflies, and analyze the sensitivity and correlation between the targets, so as to make the optimized target reach the global optimum [3-4] . Therefore, combining the advantages of fireflies, this paper designs a multi-objective optimization method of carbon emission in manufacturing industry.

2 Theoretical analysis of multi-objective optimization for carbon emission manufacturing based on firefly algorithm

The multi-objective optimization process for carbon emissions based on the firefly algorithm is shown in Figure 1.

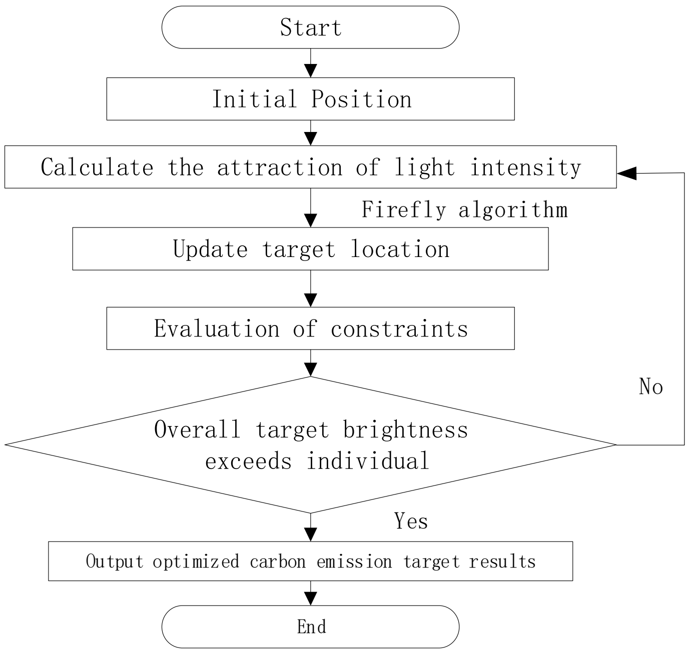

Fig 1. multi-objective optimization process for carbon emissions based on firefly algorithm

From Figure 1, it can be seen that the first step is to establish the distribution of carbon emissions targets, determine the location coordinates of manufacturing carbon emissions targets, and reflect the distribution of various targets in the multi-objective optimization model of manufacturing carbon emissions in multi-dimensional space. The carbon emission target is individual fireflies, distributed in different locations. The Firefly algorithm determines the movement and optimization process of targets based on their light intensity, and the attraction of light intensity determines the mutual influence and direction of movement between targets. As shown in Figure 2.

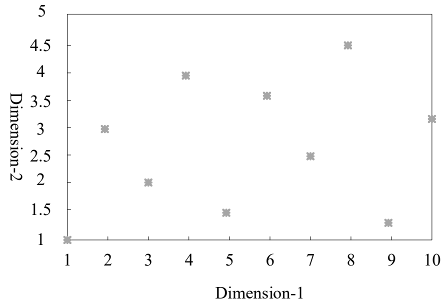

Fig 2. Schematic diagram of carbon emission target distribution

As shown in Figure 2, the dimensions of carbon emission optimization objectives of manufacturing industry are (1,1), (2,3), (3,2), (4,4), (5,1.5), (6,3.75), (7,2.5), (8,4.5) (9,1.25)、and (10,3.25) respectively. The distribution position of different fireflies is determined by the individual light intensity, and the process of searching for the best and moving is determined by the attraction of light intensity.

Then calculate the light intensity of each carbon emission target, taking into account the relationship between the original light intensity, light absorption coefficient, and carbon emission target. Calculate the light intensity attraction relationship and mutual influence between carbon emission targets based on the relative distance between individuals. Establish a multi-objective optimization model for manufacturing carbon emissions, taking into account the impact of economic growth, energy intensity, and changes in energy structure on carbon emissions. Randomly initialize the position of carbon emission targets, and determine the initial position of each carbon emission target in multidimensional space. Using the position of each carbon emission target, calculate the light intensity attraction relationship between the targets to determine their mutual attraction and movement direction. Update the position of each carbon emission target based on the calculated light intensity attraction and optimization model expression. Evaluate the constraints on the updated target location to ensure compliance with the constraints set in the manufacturing carbon emissions issue. The constraints of multi-objective optimization of carbon emissions are shown in Table 1.

Table 1. Constraints of carbon emission optimization target

Target	Constraint condition
economic growth	The average annual growth rate of manufacturing gross domestic product is 6.5%, while other factors remain unchanged
Prioritize the development of high-efficiency industries	The average annual growth rate of the manufacturing industry's gross domestic product is 6.5%. The overall industry structure is high efficiency: 36%, medium efficiency: 41%, low efficiency: 23%, and other factors remain unchanged
Reduced energy intensity	The average annual growth rate of manufacturing gross domestic product is 6.5%, energy intensity is reduced by 13.5%, and other factors remain unchanged
Energy structure optimization	The average annual growth rate of the total production value of the manufacturing industry is 6.5%, and the energy structure is optimized to 43.84% for coal and coal products, 8.55% for petroleum and petroleum products, 5.74% for natural gas, 10.34% for heating, 13.64% for secondary power, and 17.89% for primary and other energy. Other factors remain unchanged
comprehensive measures	The average annual growth rate of manufacturing gross domestic product is 6.5%, taking into account the optimization goals of 1, 2, 3, and 4, while other factors remain unchanged

Finally, based on the preset termination conditions, determine whether the conditions for terminating the iteration are met. If the termination condition is not met, recalculate the light intensity attraction and update the target position until the termination condition is met.

3 Analysis of multi-objective optimization data for carbon emission manufacturing based on firefly algorithm

The light intensity for calculating carbon emission targets is expressed as:

$$I(r) = \frac{I_0}{1+\gamma r^2} \tag{1}$$

In the formula (1), $I(r)$ is light source intensity for any target of carbon emission; I_0 is the original light intensity; γ is the light absorption coefficient; r is the carbon emission target. Based on $I(r)$ as the basic conditions, the proportional light intensity attraction between two fireflies with carbon emission targets is calculated, and the formula is as follows:

$$\beta(r) = \beta_0 \cdot e^{-\gamma r_{ij}^2} \tag{2}$$

In the formula (2), $\beta(r)$ is the direct ratio of light intensity attraction between two carbon emission target fireflies; β_0 is the light intensity attraction when the individual positions of carbon emission targets coincide; r_{ij} is the position of target I and target J. Therefore, the optimization model of carbon emission target individual is as follows:

$$R_{ij} = \sqrt{\sum_{k=1}^{n} \left(\beta(r)I(r)X_{i,n} - \beta(r)I(r)X_{j,n}\right)^2} \tag{3}$$

In the formula (3), R_{ij} is to optimize the model expression; $X_{i,n}$ is the population number of any individual I; $X_{j,n}$ is the number of groups of any individual J. Taking the distance between the two optimization targets as the benchmark value of the model, and taking economic growth, energy intensity and energy structure as the carbon emission targets, the carbon emission of manufacturing industry is optimized [5-7] . The carbon emission can still be kept at a low level under the condition of multiple objective changes, so as to meet the multi-objective optimization demand of carbon emission in manufacturing industry. Among them, when the economic growth changes, the carbon emission optimization formula is expressed as:

$$C_e = \sum_{ij} C_{ij} \cdot \ln\left(\frac{g^T}{g^0}\right) \tag{4}$$

In the formula (4), C_e is the change of economic growth factors that causes the change of carbon emissions of the manufacturing industry; C_{ij} is the carbon emission of energy J in Class

I manufacturing category; g^T is the overall industrial output value of manufacturing industry in the final state; g^0 is the overall industrial output value of manufacturing industry in the base period. When the energy intensity changes, the carbon emission optimization formula is expressed as [8-10] :

$$C_i = \sum_{ij} C_{ij} \cdot \ln\left(\frac{I_i^T}{I_i^0}\right) \tag{5}$$

In the formula (5), C_i is for the change of energy intensity, which causes the change of carbon emissions of manufacturing industry; I_i^T is for the final state, the energy intensity of Class I manufacturing category; I_i^0 is the energy intensity of Class I manufacturing in the base period. When the energy organization changes, the carbon emission optimization formula is expressed as:

$$C_s = \sum_{ij} C_{ij} \cdot \ln\left(\frac{s_{ij}^T}{s_{ij}^0}\right) \tag{6}$$

In the formula (6), C_s is for the change of energy structure, which causes the change of carbon emissions of manufacturing industry; s_{ij}^T is for the final state, the j-th energy consumption proportion in the i-th manufacturing category; s_{ij}^0 is for the base period, the j-th energy consumption proportion in the i-th manufacturing category. Under the conditions of economic growth, energy intensity and energy structure changes, a multi-objective optimization model of manufacturing carbon emissions has been formed. At this time, the smaller the carbon emission of C_e 、 C_i 、 C_s , the better the multi-objective optimization effect of carbon emission, and the higher the completion degree of carbon emission reduction task in manufacturing industry, which plays an important role in the sustainable development of manufacturing industry.

According to the change of energy structure and energy intensity, the reliability constraint of carbon emission is determined, and the formula is as follows:

$$\sum_{i=1}^{n} E_{i,k} \times (1 - \varepsilon_{i,k}) \geq I(r) \tag{7}$$

In the formula (7), $E_{i,k}$ is the carbon emission of the i manufacturing category in the k year; $\varepsilon_{i,k}$ is the energy consumption of category i manufacturing industry in k year. Make $\sum_{i=1}^{n} E_{i,k} \times (1 - \varepsilon_{i,k})$ as a whole target, the brightness of individual light sources of fireflies exceeds $I(r)$ is proved that the overall goal can reach the global optimal conditions, and the carbon emission optimization effect of manufacturing industry is better.

4 Experiment

4.1 Experimental preparation

This experiment selects the carbon emission data of manufacturing industry in recent 10 years as real data, uses SDA to decompose the data structure, judges the influencing factors of carbon emission, and optimizes the carbon emission target of manufacturing industry from the aspects of target setting, data requirements and results presentation. And the correlation degree of carbon emission optimization target of manufacturing industry is analyzed, as shown in Figure 2.

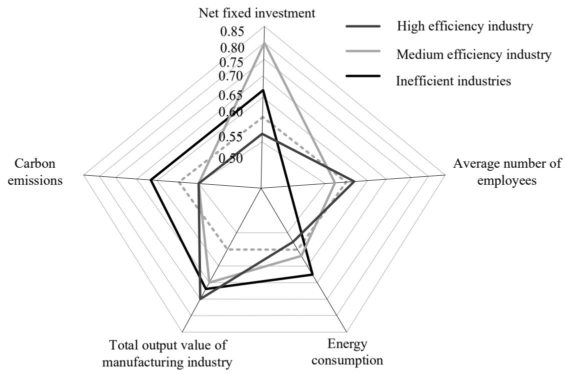

Fig 2. Correlation degree of carbon emission optimization target in manufacturing industry

As shown in Figure 2,The optimization effect of peak carbon dioxide emissions's goal is: comprehensive measures > reducing energy intensity > optimizing energy structure > optimizing the development of high-efficiency industries. Thus, the peak carbon dioxide emissions goals are set, as shown in Table 2.

Table 2. Peak carbon dioxide emissions Target Setting Data Sheet

Scene		Next 5 years		Next 10 years	
		comprehensive measures	cumulative effect	Carbon emission trends	Optimization objectives
Annual average growth rate of total output value of manufacturing industry/%		6.50	6.50	6.50	6.50
Industry Structure /%	High efficiency industry	36.00	37.16	37.16	40.00
	Medium efficiency industry	41.00	39.95	39.95	40.00
	Inefficient industries	23.00	22.89	22.89	20.00
Accumulated decrease rate of energy intensity /%		13.50	27.00	27.00	25.00
energy-resource structure /%	Coal and coal products	43.84	42.47	42.47	40.37
	Petroleum and petroleum products	8.55	8.32	8.32	8.55
	natural gas	5.74	7.00	7.00	7.15
	Thermodynamics	10.34	10.34	10.34	11.37
	secondary power	13.64	13.27	13.27	11.374
	Primary electricity and other energy sources	17.89	18.60	18.60	21.22
Reduction rate of energy carbon emission coefficient /%		/	/	12.00	12.00

4.2 Experimental results

The final experimental results are shown in Table 3.

Table 3. Experimental results

Period	Industry	Carbon emissions of conventional multi-objective optimization methods for manufacturing carbon emissions based on genetic algorithms /10^4t			Carbon emissions of conventional multi-objective optimization methods for manufacturing carbon emissions based on exergy efficiency /10^4t			The carbon emissions of the multi-objective optimization method for manufacturing carbon emissions based on the firefly algorithm designed in this article /10^4t		
		C_e	C_i	C_s	C_e	C_i	C_s	C_e	C_i	C_s
O period	G	469.78	588.59	268.78	162.26	187.63	86.34	168.74	214.92	2.97
	Z	587.98	359.54	847.68	330.99	-154.25	168.74	85.68	-500.77	251.85
	D	1258.62	168.84	-458.84	813.47	587.64	686.46	-32.52	607.65	427.66
	P	2316.36	1116.97	657.62	1306.72	621.02	941.54	221.90	321.79	682.47
F period	G	367.88	625.48	154.65	268.74	167.48	156.35	146.58	465.88	22.96
	Z	-185.78	-287.55	354.68	-225.47	-245.68	54.36	-658.74	-648.28	199.44
	D	854.64	-155.25	62.45	387.51	-54.88	-245.58	574.85	-126.87	-485.93
	P	1036.74	182.68	571.78	430.78	-133.08	-34.87	62.69	-309.27	-263.53
T period	G	297.68	-185.48	267.48	45.68	-25.47	-14.55	154.84	-316.63	-34.61
	Z	578.98	1058.14	-56.27	468.58	587.42	-146.58	267.98	892.04	-270.97
	D	-126.58	-287.96	135.68	-145.68	164.54	-154.68	-465.88	-1117.53	-361.87
	P	750.08	584.70	346.89	368.58	726.49	-315.81	-43.06	-542.12	-667.45

As shown in Table 3, the method designed in this article can avoid local optimization, achieve global optimization, achieve better multi-objective optimization performance, and complete carbon reduction tasks in the manufacturing industry. Meets the purpose of this article.

5 Conclusion

In the context of "dual carbon", the carbon emissions of the manufacturing industry urgently need to be optimized. Therefore, this article uses the Firefly algorithm to design a multi-objective optimization method for manufacturing carbon emissions. Reduce carbon emissions from both optimization models and energy constraints, and achieve carbon emission reduction goals.

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