Multi-Objective Optimization Model of Industrial Structure under Dual-Carbon Background: a Case Study of S Province

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Abstract. Under the dual-carbon background, in order to achieve high-quality development in each province, it is necessary to rationally optimize the industrial structure in conjunction with the demand for low-carbon emissions to achieve green and sustainable development. Firstly, taking S province as an example, the industrial structure of S province is subdivided into four major categories: agriculture, forestry, animal husbandry and fishery, industry, construction and service industry, in order to formulate policies and strategies in a more targeted way; secondly, based on the historical data, a multi-objective optimization model of industrial structure under the dual-carbon background is constructed, taking the scale of the economy, the intensity of carbon dioxide, and the total amount of energy consumption as the constraints; lastly, the empirical analysis validates the model's impact on the economy and the environment, so as to provide valuable reference basis for S province to realize low-carbon economic development under the dual-carbon background.

Keywords: industrial structure; multi-objective optimization; low-carbon economy

1 Introduction

With the growth of the economy and the continuous improvement of the income level of the residents, the cumulative effect of the energy demand and consumption by economic activities increases the energy consumption year by year. Under the dual-carbon background, in order to achieve high-quality development, provinces need to rationally optimize the industrial structure in combination with the demand for low-carbon emissions to achieve green and sustainable development.

With the implementation of the concept of sustainable development, many scholars have studied the issue of carbon emission reduction in economic growth. Literature[1] has deeply analyzed the relationship between carbon dioxide emissions and economic growth. It is found that the decoupling of carbon emission and economic growth can be realized through industrial structure upgrading and technological innovation. Literature [2] studied the strategy of promoting the construction of low-carbon cities through the optimization of industrial structure, and found that the adjustment of industrial structure can significantly reduce the level of carbon emissions. Literature [3] found that the adjustment of industrial structure and the introduction of green technology can realize sustainable economic development. Literature [4] explored the impact of industrial structure adjustment on carbon emissions based on provincial panel data. The

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findings show that the carbon emission level can be significantly reduced by optimizing the industrial structure. In the study of industrial structure optimization under low carbon constraints, literature [5] points out that the requirements of low carbon economy can be achieved through the adjustment of industrial structure. Literature [6] explored the relationship between energy and economic growth by constructing a comprehensive index. The study concluded that the coordinated development of economic growth and carbon emission reduction can be achieved through the optimization of industrial structure and the improvement of energy use efficiency. Therefore the differences in the degree of energy dependence and carbon emission efficiency of various industries cannot be ignored and need to be studied in depth.

In summary, in order to improve the accuracy and rationality of industrial structure optimization, this paper constructs a multi-objective optimization model of industrial structure under the dual-carbon background based on historical data and taking economic scale, carbon dioxide intensity, total energy consumption and other constraints as an example of S province, which provides certain reference for the development of S province's low-carbon economy under the dual-carbon background.

2 Multi-objective optimization of industrial structure

2.1 Model construction

In the study of industrial structure optimization in S Province, this paper subdivides the industries into: agriculture, forestry, animal husbandry and fishery, industry, construction industry and service industry. Based on the historical data, this paper takes the optimization model with the largest economic aggregate, the minimum energy consumption and the minimum carbon dioxide emission intensity as the target function, constructs the multi-objective optimization model of industrial structure under dual-carbon background.

2.2 Objective function

This paper sets the target function according to the positive and negative deviation variables of the economic aggregate, the positive and negative deviation variables of carbon dioxide emission intensity and the positive and negative deviation variables of the positive and negative deviation of energy consumption.

$$\min Q_t = \gamma_1 * (d_{1,t}^- - d_{1,t}^+) + \gamma_2 * (d_{2,t}^+ - d_{2,t}^-) + \gamma_3 * (d_{3,t}^+ - d_{3,t}^-) \quad (1)$$

Where Q_t is the value of the moment objective function; $d_{1,t}^-$、 $d_{2,t}^+$ and $d_{3,t}^+$ are the negative deviation value of the total economic volume, the positive deviation value of the carbon dioxide emission intensity and the positive deviation value of the energy consumption in the year t, respectively; γ_1、 γ_2 and γ_3 are the weights of the negative deviation value of the total economic volume, the positive deviation value of the carbon dioxide emission intensity and the positive deviation value of the energy consumption, respectively. In this paper, the three objective functions are unity of opposites and the realization of the three objectives should be taken into account, so the three objective functions are given the same weights, i.e. 1/3, 1/3 and 1/3.

(1) Economic level constraints

In the first year of t, the total GDP of S province is the sum of the added value of eight industries, including agriculture, forestry, animal husbandry and fishery, energy-intensive industries, equipment manufacturing, other industries, construction, transportation, storage and postal service, information transmission, software and information technology service industry, wholesale and retail, accommodation and catering industry:

$$\begin{cases} GDP_t = \sum_{i=1}^{8} GDP_{i,t} \\ GDP_{i,t} - d_{1,i,t}^{+} + d_{1,i,t}^{-} = GDP_{i,t,\text{base}} \\ d_{1,t}^{+} = \sum_{i=1}^{8} d_{1,i,t}^{+},\ \ d_{1,t}^{-} = \sum_{i=1}^{8} d_{1,i,t}^{-} \end{cases} \tag{2}$$

Where $GDP_{i,t}$ and $GDP_{i,t,\text{base}}$ denote the actual level of GDP in year t of industry i and the benchmark value; $d_{1,i,t}^{+}$ and $d_{1,i,t}^{-}$ denote the positive and negative deviation of the actual level of GDP in year t of industry i from the benchmark value; t=2023,2024,...

2060，i=1,2, ... ,8.

(2) Industrial structure constraints

In the long term, the proportion of agriculture, forestry, animal husbandry, fishery, industry and construction in S province is less than or equal to the minimum proportion of historical added value; the proportion of service industry is greater than or equal to the maximum proportion of historical added value.

$$\begin{cases} GDP_{i,t} \le GDP_{i,t} / \sum_{i=1}^{8} GDP_{i,t}, i = 1,2,3,4,5 \\ GDP_{i,t} \ge GDP_{i,t} / \sum_{i=1}^{8} GDP_{i,t}, i = 6,7,8 \end{cases} \tag{3}$$

(3) Carbon emission intensity constraints

According to the Action Plan issued by the S Provincial People's Government, by 2030, carbon dioxide emissions per unit of GDP will be reduced by more than 68 percent compared with 2005, to ensure that the carbon peak target by 2030 will be achieved as scheduled.

$$\begin{cases} C_{i,t} - d_{2,i,t}^{+} + d_{2,i,t}^{-} = C_{i,t,\text{base}} \\ d_{2,t}^{+} = \sum_{i=1}^{8} d_{2,i,t}^{+},\ \ d_{2,t}^{-} = \sum_{i=1}^{8} d_{2,i,t}^{-} \\ \sum_{i=1}^{8} C_{i,2030} / \sum_{i=1}^{8} GDP_{I,2030} \le (1-68\%) * (\sum_{i=1}^{8} C_{i,2005} / \sum_{i=1}^{8} GDP_{i,2005}) \end{cases} \tag{4}$$

Where $C_{i,t}$ and $C_{i,t,\text{base}}$ denote the actual carbon emissions and baseline carbon emissions of industry i in year t, respectively.

(4) Energy consumption constraint

According to the 14th Five-Year Plan for Energy Development in S Province, the total energy consumption should be controlled within 454 million tons of standard coal in 2025. Energy consumption constraints are as follows:

$$\begin{cases} E_{i,t} - d_{3,i,t}^{+} + d_{3,i,t}^{-} = E_{i,t,\text{base}} \\ d_{3,t}^{+} = \sum_{i=1}^{8} d_{3,i,t}^{+}, d_{3,t}^{-} = \sum_{i=1}^{8} d_{3,i,t}^{-} \\ 0 \le \sum_{i=1}^{8} E_{i,2025} \le 45400 \\ \sum_{i=1}^{8} E_{i,2025} = (1-14.5\%) * \sum_{i=1}^{8} E_{i,2020} \end{cases} \tag{5}$$

Where $E_{i,t,\text{base}}$ is the total baseline energy consumption of industry *i* in year *t*.

(5) Non-negative condition constraints

$$\begin{cases} GDP_{i,t}, E_{i,t}, C_{i,t}, d_{1,i,t}^{+}, d_{1,i,t}^{-}, d_{2,i,t}^{+}, d_{2,i,t}^{-}, d_{3,i,t}^{+}, d_{3,i,t}^{-} \ge 0 \\ 0 \le u_{1,i,t}^{+} d_{1,i,t}^{+} + u_{1,i,t}^{-} d_{1,i,t}^{-} \le 1 \\ 0 \le u_{2,i,t}^{+} d_{1,i,t}^{+} + u_{2,i,t}^{-} d_{1,i,t}^{-} \le 1 \\ 0 \le u_{3,i,t}^{+} d_{1,i,t}^{+} + u_{3,i,t}^{-} d_{1,i,t}^{-} \le 1 \end{cases} \tag{6}$$

Where $u_{1,i,t}^{+}$ and $u_{1,i,t}^{-}$ denote the state variables for positive and negative deviations of economic aggregates (0-1 variables); $u_{2,i,t}^{+}$ and $u_{2,i,t}^{-}$ 分 denote the state variables for positive and negative deviations of carbon emissions; $u_{3,i,t}^{+}$ and $u_{3,i,t}^{-}$ denote the state variables for positive and negative deviations of energy consumption, respectively.

3 Empirical analysis

3.1 Data source and processing

This paper data from the statistical yearbook of S province, the S national economic and social development statistical bulletin, this paper selects 2002-2022 in S province industry GDP, carbon intensity and energy consumption coefficient, using the grey GM (1,1) prediction model, predict its 2023-2060 value (base period for 2002), and the forecast value as a benchmark numerical into constraints (shown as **Table 1**), used in the optimization model.

Table 1. Base values of the main indicators

Year	Total GDP benchmark value of S Province (comparable price) / 100 million yuan	S province GDP growth rate benchmark value /%	S province energy consumption benchmark value / 10,000 tons of standard coal	Benchmark carbon emission value of S Province / ten thousand tons
2023	36732.694	5.58	40365.07	58746.48

2024	38753.06574	5.50	41006.05	59835.77
2025	40752.24032	5.16	41657.21	58998.44
2026	42714.58263	4.82	42318.70	59116.72
2027	44722.82998	4.70	42990.70	59311.73
2028	46776.70021	4.59	43673.38	57581.61
2029	48875.90236	4.49	44366.89	56241.27
2030	51020.13464	4.39	45071.41	52028.19
2031	53204.97142	4.28	45787.13	51768.47
2032	55430.08393	4.18	46514.20	50707.25
2033	57695.17027	4.09	47252.83	49577.22
2034	59999.95972	3.99	48003.18	48357.74
2035	62344.21159	3.91	48765.45	45847.27
2036	64719.44151	3.81	49539.82	45867.06
2037	67131.35047	3.73	50326.49	43994.04
2038	69579.66934	3.65	51125.65	42192.58
2039	72064.17289	3.57	51937.50	40459.50
2040	74584.67782	3.50	52762.24	36053.49
2041	77130.62357	3.41	53600.08	35792.10
2042	79701.81259	3.33	54451.23	33672.45
2043	82298.14938	3.26	55315.89	31556.03
2044	84919.64674	3.19	56194.28	29441.08
2045	87566.41811	3.12	57086.62	26822.40
2046	90245.00236	3.06	57993.12	25511.04
2047	92955.65917	3.00	58914.03	23087.66
2048	95698.7206	2.95	59849.55	20816.56
2049	98474.58848	2.90	60799.94	18694.16
2050	101283.738	2.85	61765.41	19132.02
2051	104121.8831	2.80	62746.22	18578.43
2052	106989.7422	2.75	63742.60	17426.57
2053	109888.124	2.71	64754.80	16318.19
2054	112817.9276	2.67	65783.08	15251.16
2055	115780.143	2.63	66827.68	14077.08
2056	118776.2919	2.59	67888.87	14929.22
2057	121807.5242	2.55	68966.91	14368.87
2058	124875.078	2.52	70062.08	13823.84
2059	127980.2747	2.49	71174.63	13293.64
2060	131124.5182	2.46	72304.85	12772.20

3.2 Analysis of the optimization results

This paper focuses on 8 categories of sub-industries, and further analyzes the optimized industrial structure. After the optimization, the added value of various industries is accounted for as shown in **Fig.** 1. The optimized industrial structure is relatively reasonable. The proportion of added value of agriculture, forestry, animal husbandry and fishery and the proportion of construction industry fluctuates within the range of [7%-8%], accounting for a relatively small proportion in the total economic aggregate. Industrial output fluctuated between 18% and 33%. Compared with agriculture, forestry, fishery and animal husbandry, industry has a larger share in the economic aggregate. After 2032, the proportion of industry will decrease year by year, and the proportion of the added value of the service industry will increase year by year, accounting for the largest proportion among all industries. Compared with resource-intensive industries, the service industry has a low negative impact on the environment, which is conducive to achieve the sustainable development goal of S Province and reduce the excessive consumption of natural resources. To sum up, the economy of S province experienced a stage from fluctuation change to stable growth from 2023 to 2060. Under the guidance of the national energy conservation and emission reduction targets, the proportion of added value of energy-intensive industries gradually decreased, the added value of wholesale, retail, accommodation and catering industries increased year by year, and the industrial structure became more reasonable.

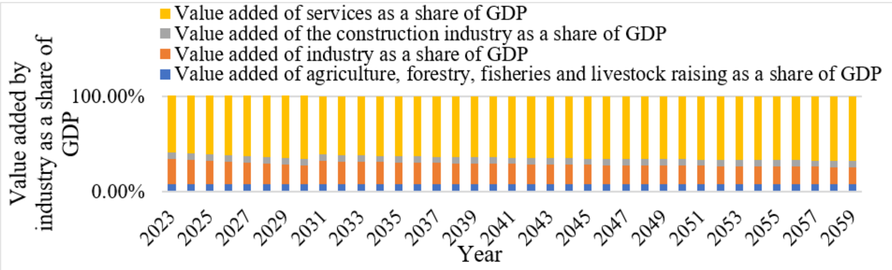

Fig. 1 The proportion of the added value of sub-industries in the total GDP of S Province

4 Conclusion

In order to optimize the industrial structure of S Province, this paper constructs a multi-objective optimization model to optimize the industrial structure of S province under the background of dual carbon, so as to achieve the goal of carbon reduction and emission reduction. To maintain the steady increase of the proportion of tertiary industry in the GDP of S province is conducive to reducing carbon emissions in industrial development, which is an important link in the implementation of the national green development strategy.

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References

[1] Xiaoling Wang, Yawen Wei, Qinglong Shao. Decomposing the decoupling of CO2 emissions and economic growth in China iron and steel industry[J]. Resources, Conservation and Recycling,2020(152):104509.

[2] Chen, W.,Liu, J.,Ning, X., Du, L., Zhang, Y.,Wu, C. Low-Carbon City Building and Green Development: New Evidence from Quasi Natural Experiments from 277 Cities in China[J]. Sustainability ,2023(15):11609.

[3] Mohammad Mafizur Rahman, Mohammad Abul Kashem. Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and Granger causality analysis[J]. Energy Policy,2017, 110.

[4] Onofrei Mihaela, Vatamanu Anca Florentina, Cigu Elena. The Relationship Between Economic Growth and CO2 Emissions in EU Countries: A Cointegration Analysis[J].2022(10):934885.

[5] Eddy Bekkers, Robert B. Koopman, Carolina Lemos Rêgo. Structural change in the Chinese economy and changing trade relations with the world[J]. China Economic Review,2021(65):101573.
[6] Chaoyi Chen, Mehmet Pinar, Thanasis Stengos. Renewable energy consumption and economic growth nexus: Evidence from a threshold model[J]. Energy Policy,2020(139):111295.