Study on the evaluation and transformation path of green industrial development in Sichuan Province

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Abstract. This paper calculated the green index of 37 industries in Sichuan province by constructing a comprehensive model reflecting the economic contribution rate and environmental pollution contribution rate of industry, and the K-means method was used for clustering analysis. The results show that the green index of industry in Sichuan is at a good level among the country, but there is still a large development space. Based on the green index of clustering results show that the industry is divided into 4 major categories: encouraged development, optimized development, allowed development and restricted development, and the differentiated countermeasures proposed by the paper based on the research results are the practical needs of the green development of industries in the new era.

1. Introduction

Standing at the intersection of two centuries, China is about to embark on a new journey of building the modern socialist country. Accelerating the construction of ecological civilization and building a beautiful China has become a consensus at home and abroad. As the main field of economic activity, the industry has always been the focus of research on ecological environmental protection and sustainable development. Green transformation and upgrading has become the only way for industrial development in the new period[1].

Relevant studies have shown that the internal structure of the industry is the main factor affecting the green and sustainable development, so the optimization and adjustment of the industrial structure has also become the hotspots of domestic and foreign scholars. Many researchers analysed and evaluated the industrial green development level of different scales and regions by using various characteristic indicators[1-11]. They discussed the correlation between industrial structure and environmental pollution, and pointed out the necessity and the implementation measures of optimizing and upgrading the industrial structure. These results provided a scientific basis for the transformation and upgrading of China’s industry. However, these exploratory research methods and results were too scattered, and none of them could comprehensively reflect the overall contribution of the industry to the environment and the economy and their interrelationships, and it was difficult to guide the adjustment, transformation and upgrading of the industrial structure in practice. To this end, this article attempted to construct a green index that could comprehensively reflect the environmental and economic characteristics of the industry. We not only analysed the current status and problems of the green development of various
industries, but also provided science for the green transformation and upgrading of our country’s industry. Through analysis, the development of research and practice in this field had been promoted.

2. Research Methods

2.1. Construction of Green Index

Green industry is an industrial economic model with the fundamental objective of sustainable development, which takes technological innovation as its core and adopts a series of resource recycling methods to comprehensively protect the environment. It considers the comprehensive benefits of economy, society, energy, environment, and technology. Green industry is an industrial form that maintains the continuous growth of industrial economy and the sustainability of resources and the environment. It is characterized by efficient use of resources, low pollution emissions, technological innovation, and good social and economic benefits[1].

In order to reflect the level and characteristics of green industries in different industries, this article defined the "green index" as the ratio of the economic contribution rate of the industry to the environmental pollution contribution rate, and established an intuitive basis for the green analysis of the industrial structure. The formula is as follows:

\[
I_i = \frac{A_i}{B_i} \quad (Bi \neq 0)
\]

Where \(I_i\) represents the green index of the i-th industry, \(A_i\) represents the economic contribution rate of the i-th industry, and \(B_i\) is the environmental pollution contribution rate of the i-th industry. According to the principle of conservation of quality, the general industrial process is limited by technology, and there will be a certain amount of pollution. Therefore, this article did not consider the situation of \(B_i=0\).

2.2. Calculation of Green Index

2.2.1. Economic contribution rate. The economic contribution rate is a positive indicator for analysing the economic benefits of the industry. Industrial production conditions, production technologies, labor force and management levels are all influential factors. This contribution rate is also an important basis for judging whether an industry is a sunrise industry or a growth industry.

In this paper, the ratio of the comprehensive output value of the i-th industry to the total comprehensive output value of the industry was used as the economic contribution rate of the i-th industry, namely:

\[
A_i = \frac{F_i}{\sum F_i}
\]

Where \(A_i\) represents the economic contribution rate of the i-th industry, \(F_i\) represents the comprehensive output value of the i-th industry.

The comprehensive-industrial output value is a comprehensive index. This paper selected three factors listed in Table 1 as the corresponding indicators for the comprehensive economic value of industry i. These three indicators show the economic benefits of an industry, on the other hand, it also reflects its contribution to the development of national economy.

| Number | Indicator name            | Unit              | Reflect content               |
|--------|---------------------------|-------------------|-------------------------------|
| 1      | Main business income      | 100 million yuan  | Profitability                 |
| 2      | Tax revenue               | 100 million yuan  | Economic quality and efficiency|
| 3      | Average number of workers | Ten thousand people| employment status            |
When calculating $F_i$, first standardized the index data with the maximum-minimum method, eliminated the dimensions, and added weighted sums to obtain the comprehensive output value of the $i$-th industry, that is, the comprehensive economic value of the $i$-th industry, namely:

$$F_i = \sum_{j=1}^{n} S_{ij} \times W_j \quad (3)$$

Where $S_{ij}$ is standardized data, $W_j$ represents weight of each indicator, $n$ represents number of indicators.

2.2.2. Environmental pollution contribution rate

The contribution rate of environmental pollution is a negative indicator to measure the environmental friendliness of the industry, which can reflect the current environmental status of the industry, as well as the level of clean production and pollution control, and the effectiveness of management. When the contribution of pollution is large, the industry will inevitably become a key control object, it will limit growth and lower the economic level.

In this paper, the ratio of the comprehensive value of pollution emissions of $i$-th industry to the comprehensive value of total industrial pollution emissions was set as the environmental pollution contribution rate, namely:

$$B_i = \frac{C_i}{\sum C_i} \quad (Ci\neq0) \quad (4)$$

Where $B_i$ represents environmental pollution contribution rate of $i$-th industry; $C_i$ is comprehensive value of pollution emission of $i$-th industry.

The comprehensive value of pollution emissions is also a comprehensive indicator reflecting the pollution contribution of the industry. In order to fully consider the pollution status of the industry, this paper selected the emissions data of the eight environmental indicators shown in Table 2. These eight indicators not only include the main conventional pollutants such as COD, SO2, but also cover the total pollutant emission control indicators stipulated by China, which can more comprehensively reflect the pollution discharge status of the industry.

| Number | Indicator name            | Unit                   | Reflect content                                      |
|--------|---------------------------|------------------------|------------------------------------------------------|
| 1      | Industrial wastewater     | Ten thousand tons      | Main pollutants in industrial wastewater             |
| 2      | COD                       | Ton                    |                                                      |
| 3      | NH$_3$-N                  | Ton                    |                                                      |
| 4      | Industrial waste gas      | One hundred million cubic meters |                                                      |
| 5      | SO$_2$                    | Ton                    | Main pollutants in industrial waste gas              |
| 6      | NO$_x$                    | Ton                    |                                                      |
| 7      | Smoke (powder) dust emissions | Ton                |                                                      |
| 8      | Industrial solid waste production | Ten thousand tons  | Industrial general solid waste and hazardous waste |

When calculating $C_i$, it was the same as calculating $F_i$ (formula 3), first standardized the index data, and then the weights of each index were correspondingly multiplied and summed to obtain the comprehensive value of pollution emissions in the $i$-th industry.

2.2.3. Green Index

Formulas (2) ~ (4) show the calculation methods of economic contribution rate and environmental pollution contribution rate. Combining them with formula (1), a detailed formula for constructing the green index can be obtained, namely:

$$I_i = \frac{A_i}{B_i} = \frac{\sum F_i}{\sum C_i} \quad (Ci\neq0, Bi\neq0) \quad (5)$$
Generally, industries with a green index greater than 1 indicate that their economic contribution rate is higher than that of environmental pollution and is more suitable for long-term development. The larger the green index, the more encouraging the development of the industry. The industry with a green index less than 1, the smaller the green index, The lower the green level.

2.3. Cluster analysis

Different industries have different environmental and economic characteristics. Some industries have higher economic benefits but also have obvious impacts on the environment. Although some industries have low economic benefits, they are required by the national economy and have a small amount of pollutants. In order to analyse the green level of various industries in a more objective and in-depth manner, it is necessary to reclassify the industries according to the difference in the economic contribution rate and environmental pollution contribution rate of each industry. In this paper, each industry was clustered and analysed according to economic contribution rate and environmental pollution contribution rate.

Cluster analysis is a method of multivariate statistical analysis. First let the original data be:

\[
\begin{bmatrix}
  x_{11} & \cdots & x_{1m} \\
  \vdots & \ddots & \vdots \\
  x_{n1} & \cdots & x_{nm}
\end{bmatrix}
\]

\(x_i = (x_{i1}, x_{i2}, \ldots, x_{im})^T, x_j = (x_{j1}, x_{j2}, \ldots, x_{jm})^T\) are the observation values of the i-th and the j-th samples. The distance between the two is:

\[d_{ij} = \sqrt{\sum_{k=1}^{m} (x_{ik} - x_{jk})^2}\] (6)

Then according to the distance, mathematical methods are used to determine the close relationship between samples quantitatively, and then classify the types based on common characteristics scientifically and objectively[12].

K-means clustering algorithm has fast and high efficiency, so it is widely used when clustering large amounts of data. Due to the large amount of data in this article, and the two characteristics of economic contribution and environmental pollution contribution had been clarified, so the K-means clustering method was finally selected for clustering analysis. According to the permutation and combination of characteristics, 37 industries could be divided into 4 types.

3. Data Source

This article took 37 industries in Sichuan Province as an example, and compared 37 industries across the country. The required calculation indicators included economic indicators and environmental indicators. For economic indicators, we selected the main business income, tax revenue and average number of workers in various industries in Sichuan Province and China in 2017 as corresponding indicators; for environmental indicators, eight flow indicators in 2017 were selected, which were industrial wastewater, COD, NH3-N, industrial waste gas, SO2, NOX, smoke (powder) emissions and industrial solid waste production. The data came from the "2018 China Statistical Yearbook on Environment", "2018 China Taxation Yearbook", "2018 China Industry Statistical Yearbook" and statistics from the Sichuan Academy of Environmental Sciences.

4. Results and Discussion

4.1. Analysis of Green index calculation results

Using the environmental and economic data of Sichuan Province and the whole country, the economic contribution rate, environmental pollution contribution rate and green index of 37 industries in Sichuan Province and the whole country could be obtained by calculating respectively according to formulas (2) ~ (5). The industrial sectors in Sichuan Province were sorted according to their green index, and compared with the average level of various industries in the country, as is shown in Table 3.
Table 2. Contribution rate of economic and environmental pollution and green index of various industries.

| Serial number | Industry                                                                 | Economic contribution rate | Environmental pollution Contribution rate | Green Index of Sichuan | Green Index of China |
|---------------|--------------------------------------------------------------------------|----------------------------|-------------------------------------------|------------------------|---------------------|
| 1             | Cultural, Educational, Industrial and artistic, Sports and Entertainment Products Manufacturing Tobacco products industry | 0.312%                    | 0.008%                                    | 40.56                  | 36.63               |
| 2             | Tobacco products industry Instrumentation Manufacturing                   | 2.320%                    | 0.099%                                    | 23.52                  | 5.51                |
| 3             | Electrical machinery and equipment manufacturing Special equipment manufacturing industry | 0.299%                    | 0.014%                                    | 21.39                  | 13.95               |
| 4             | Automotive Manufacturing                                                | 3.341%                    | 0.173%                                    | 19.33                  | 20.02               |
| 5             | Furniture manufacturing                                                    | 3.214%                    | 0.227%                                    | 14.13                  | 14.75               |
| 6             | General equipment manufacturing                                          | 4.881%                    | 0.433%                                    | 11.28                  | 10.83               |
| 7             | Food processing and wood, bamboo, rattan, palm and grass products industry | 6.031%                    | 0.546%                                    | 11.04                  | 10.70               |
| 8             | Computer, communications and other electronic equipment manufacturing      | 1.675%                    | 0.173%                                    | 9.70                   | 5.37                |
| 9             | Railway, shipbuilding, aerospace and other other electronic equipment manufacturing | 2.273%                    | 0.382%                                    | 5.96                   | 6.31                |
| 10            | Transportation equipment manufacturing Computer, communications and other electronic equipment manufacturing | 1.538%                    | 0.299%                                    | 5.14                   | 5.29                |
| 11            | Wood processing and wood, bamboo, rattan, palm and grass products industry | 8.548%                    | 1.664%                                    | 5.14                   | 6.46                |
| 12            | Textile and Apparel, Apparel Industry Printing and recording media reproduction industry | 0.906%                    | 0.225%                                    | 4.03                   | 3.99                |
| 13            | Oil and gas extraction industry                                           | 0.651%                    | 0.167%                                    | 3.89                   | 4.37                |
| 14            | Metal products industry                                                   | 1.032%                    | 0.318%                                    | 3.24                   | 1.55                |
| 15            | Non-metallic mineral products industry                                   | 1.605%                    | 0.732%                                    | 2.19                   | 1.78                |
| 16            | Non-metallic mineral products industry                                   | 2.533%                    | 1.201%                                    | 2.11                   | 1.58                |
| 17            |                                                                         | 7.252%                    | 3.677%                                    | 1.97                   | 1.89                |
|   | Industry                                                                 | 2019 (%) | 2020 (%) | 1.02  | 1.01  |
|---|--------------------------------------------------------------------------|----------|----------|-------|-------|
| 18| Non-metallic mining and dressing industry                                | 1.044%   | 0.551%   | 1.90  | 1.52  |
| 19| Leather, fur, feathers and their products and footwear industry          | 1.045%   | 0.564%   | 1.85  | 2.07  |
| 20| Other mining industries                                                  | 0.003%   | 0.002%   | 1.79  | 0.83  |
| 21| Petroleum processing, coking and nuclear fuel processing industries      | 2.241%   | 2.189%   | 1.02  | 0.94  |
| 22| Other manufacturing industry                                             | 0.476%   | 0.477%   | 1.00  | 4.58  |
| 23| Electricity and heat production and supply industry                      | 6.580%   | 6.828%   | 0.96  | 0.59  |
| 24| Pharmaceutical manufacturing                                            | 3.329%   | 3.522%   | 0.95  | 0.65  |
| 25| Food manufacturing                                                       | 2.531%   | 2.831%   | 0.89  | 0.90  |
| 26| Coal mining and washing industry                                        | 3.395%   | 3.986%   | 0.85  | 0.68  |
| 27| Non-ferrous metal smelting and pressing industry                        | 1.300%   | 1.596%   | 0.81  | 0.48  |
| 28| Agricultural and sideline food processing industry                       | 5.414%   | 7.041%   | 0.77  | 0.85  |
| 29| Textile industry                                                        | 2.295%   | 3.247%   | 0.71  | 0.89  |
| 30| Ferrous metal smelting and rolling processing industry                   | 4.743%   | 8.099%   | 0.59  | 0.41  |
| 31| Chemical raw materials and chemical products manufacturing              | 5.630%   | 10.329%  | 0.55  | 0.53  |
| 32| Liquor, beverage and refined tea manufacturing                           | 6.380%   | 12.276%  | 0.52  | 0.57  |
| 33| Non-ferrous metal mining and dressing industry                           | 0.692%   | 2.301%   | 0.30  | 0.17  |
| 34| Chemical fiber manufacturing                                            | 0.455%   | 1.664%   | 0.27  | 0.27  |
| 35| Ferrous metal mining and dressing industry                               | 1.091%   | 4.084%   | 0.27  | 0.17  |
| 36| Paper and Paper Products Industry                                       | 1.124%   | 5.722%   | 0.20  | 0.21  |
| 37| Gas production and supply industry                                       | 1.820%   | 12.355%  | 0.15  | 0.05  |

It can be seen from the table that the green index of various industries in Sichuan Province is not inferior to the national average, the technical level and pollution prevention and control efforts have been greatly improved. Among the industries, cultural, educational, industrial and artistic, sports and
entertainment products manufacturing, electrical machinery and equipment manufacturing, Special
equipment manufacturing, automobile and other transportation equipment manufacturing, computer and
other electronic equipment manufacturing industries are highly green, while coal mining, metal smelting,
chemical fiber, Papermaking, metal mining, and gas production and supply industries have a low degree
of greenness.

Sichuan Province still lags behind in traditional industries such as energy, metallurgy, chemical
industry, light industry, and building materials. The pollution contribution of them cannot be ignored.
At the same time, the governance of heavy-polluting industries also requires appropriate technology and
strength, the government's policy formulation, supervision and law enforcement capabilities need to be
improved. The two major sectors of heavy-polluting industries and advanced manufacturing are the
difficult areas of industrial development in Sichuan Province, and they are the key to reducing
environmental pollution and forming a green industrial system.

4.2. Analysis of Cluster analysis results
The economic contribution rate and pollution contribution rate of 37 industries in Sichuan Province were
analysed using the K-means clustering method in the non-hierarchical clustering method. The results
are shown in Table 4.

Table 3. Cluster analysis results.

| High contribution to the economy | Low contribution to the economy |
|---------------------------------|---------------------------------|
| ① Electrical machinery and equipment manufacturing Special equipment manufacturing industry Automotive Manufacturing General equipment manufacturing Rubber and plastic products industry Railway, shipbuilding, aerospace and other transportation equipment manufacturing Furniture manufacturing Metal products industry Tobacco products industry | ② Printing and recording media reproduction industry Cultural, Educational, Industrial and artistic, Sports and Entertainment Products Manufacturing Textile and Apparel, Apparel Industry Other manufacturing Instrumentation Manufacturing Wood processing and wood, bamboo, rattan, palm and grass products industry Other mining industries |
| ③ Computer, communications and other electronic equipment manufacturing Non-metallic mineral products industry Electricity and heat production and supply industry Liquor, beverage and refined tea manufacturing Chemical raw materials and chemical products manufacturing Agricultural and sideline food processing industry | ④ Textile industry Petroleum processing, coking and nuclear fuel processing industries Oil and gas extraction industry Gas production and supply industry Non-ferrous metal smelting and pressing industry Paper and Paper Products Industry |
On the basis of the environmental and economic characteristics determined by the economic and pollution contributions of various industries, the clustering method divided them into four major sectors: encouraged development, optimized development, allowed development, and restricted development. According to the meaning and requirements of the green index and green industry, we proposed the development path of differentiated transformation and upgrading of each sector:

- **Encouraged development category**: these industries have high economic contribution but low pollution contribution, most of them are advanced manufacturing and high-tech industries. Green innovation should be at the core, especially in places like Chengdu, Deyang and Mianyang, which are dominated by advanced manufacturing. The government should provide financial and policy support, increase innovation incentive mechanism, and establish research and development fund, technology reform fund, and new product trials fund; moreover, the government should enhance the capability of independent innovation in Sichuan Province, strengthen the intensification and refinement of manufacturing industry, and conform to the trend of "Internet +". With the help of leading scientific research institutions and universities, the government will comprehensively build national and provincial experimental bases and engineering R&D centres with green innovation as the core to overcome difficult technologies such as intelligent manufacturing. The government will also focus on cultivating leading figures and core talents and sending them to other regions.

- **Allowed development category**: this type of industry possesses low economic contribution and low pollution contribution, most of which are light industries. On the basis of improving the technical level of the entire industry, the degree of industrial agglomeration should be enhanced, and large-scale production should be increased, so that small enterprises and related large enterprises can join forces to form supporting services and industrial alliances. The government should strictly restrict the development of industrial enterprises outside the industrial park, guide labour-intensive enterprises to concentrate in the park, make full use of the advantages of infrastructure, technology, talents, and market brought by the gathering, so as to accelerate the transformation and upgrading of enterprises in competition and cooperation, and avoid overcapacity and form healthy competition and sustainable development among similar enterprises.

- **Optimized development category**: It is composed of industries with high economic contribution and high environmental pollution contribution, such as basic industries. The government should control the total energy consumption and assess the energy conservation of major energy-consuming enterprises, meanwhile extend the upstream and downstream associated enterprises to develop a circular economy and make full use of materials and energy. What’s more, the government should intensify technological transformation, increase factor utilization rate, waste utilization rate, industrial water recycling rate, etc. It is necessary to focus on strengthening the implementation of cleaner production and conducting cleaner production audits and assessments; the government should strengthen the supervision of enterprises and financial and technical support for pollution control, the industry will be transformed into the green industry while maintaining the advantages and brands of basic industries.

- **Restricted development**: This type of industry has low economic contribution but high pollution contribution. It is the key point of transformation and upgrading. In principle, no additional
production scale will be added, and small scattered enterprises will be shut down. In particular, ore mining, metallurgy and other industries with the highest emissions of wastes require strict supervision and control. The government should prohibit the production of non-standard processes and products, eliminate or upgrade the backward processes as soon as possible. These industries will innovate the production mode, implement part of the process outsourcing service and unified production so as to reduce pollution generation links; the government will impose emission permits and control on large polluting enterprises, strictly limit the total amount of their emissions. Meanwhile, for illegal enterprises, the joint law enforcement of administration and justice should be strengthened. Relevant policies will be issued to guide and force enterprises to transform and upgrade.

5. Conclusion
This paper constructed the "Industry Green Index" and its calculation method, explored a concise approach to guide industrial green transformation and upgrading by comprehensive environmental and economic indicators. The following conclusions were drawn through the research:

- For the first time, the paper defined the "Industry Green Index " as the ratio of the economic contribution rate of each industry to the environmental pollution contribution rate. The economic contribution rate was obtained by the ratio of the comprehensive industrial output value of each industry, while the environmental pollution contribution rate was obtained by the ratio of the comprehensive pollution emission value of each industry. The index is simple, clear and universal, and can be used to analyse the green development of various industries in the region and even the whole country.

- Calculating the green index of 37 industries in Sichuan Province and the whole country, it is found that the environmental and economic level of most industries in Sichuan Province have exceeded the national average level, which prove that Sichuan Province have achieved certain results in promoting the development of green industries. Only those industries whose environmental and economic level are lower than the national average need to be focused in the process of transformation and upgrading, such as electrical machinery and equipment manufacturing, automobile manufacturing, computer manufacturing.

- Through cluster analysis, the 37 industries in Sichuan Province are divided into four categories: encouraged, optimized, allowed, and restricted development. For industries that are encouraged to develop, the policy and financial support should be strengthened, and enhance intelligence and internationalization; for industries that are optimized to develop, focus on the promotion of production and sewage treatment technology; for industries that are allowed to develop, increase industry access standards and strengthen agglomeration and development; the government should shut down small and disorderly enterprises in industries whose development is restricted, and speed up the elimination of outdated technologies and the transformation and upgrading.

- The green development of industries is a complex system engineering. This paper only discussed the research and judgment of industrial green development from a macro perspective, which has certain reference significance for the classification and guidance of the green transformation and development of various industrial industries. The transformation and upgrading ideas and directions proposed in this article based on the industrial green index are still relatively superficial, and further research is needed in this regard.

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