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Research on the Evaluation of Green Development Efficiency of Zhejiang Province Industry under the Background of ‘Dual-carbon’

Menghui Zhang *, Jianjun Chen

College of Science, Zhejiang University of Science and Technology, Hangzhou,310023, China
*Corresponding Author: Menghui Zhang (Email: 2415233702@qq.com)

ABSTRACT

This paper collects data from 11 prefectural-level cities in Zhejiang Province from 2011 to 2020, and measures the industrial green development efficiency of each prefectural-level city in Zhejiang Province using the global Super-SBM model based on non-expected output combined with the GML index. The results show that, from a static point of view, from 2011 to 2020, the industrial green development efficiency of Zhejiang Province is still in the middle-low level, but there is an imbalance in the development of each prefecture-level city. From the dynamic point of view, except for Jinhua, the GML index is less than 1, the GML index of all the other cities is greater than 1, which indicates that the industrial green development efficiency of all the cities except Jinhua is improving, in addition, the improvement of industrial green development efficiency in Huzhou and Taizhou is the change of technical efficiency, while the improvement of industrial green development efficiency of the rest of the cities mainly depends on the technological progress.

KEYWORDS

Dual-carbon’ background; Industrial green development efficiency; Super-efficiency SBM

1. INTRODUCTION

Since the reform and opening up, China's industrialisation process has continued to move forward, but at the same time as the rapid development of the industrial economy, the rough input of resources and the large amount of industrial pollutant emissions have made environmental pollution, ecological deterioration and other problems increasingly serious [1], In addition, on November 15, 2021, the Ministry of Industry and Information Technology (MIIT) released the ‘14th Five-Year Plan’ Industrial Green Development Plan’, the plan clearly puts forward the implementation of industrial carbon peak promotion project, key regional green transformation and upgrading project and other eight projects [2]. To this end, we need to explore a dual-carbon background of China's industrial green development road, to promote industrial green transformation and sustainable economic development.

Zhejiang Province, as a large industrial manufacturing province, the gross industrial product in 2022 was 10233.11 billion yuan, ranking fourth in the country, and the annual value added of industry above designated size in 2022 was 2,190 billion yuan, an increase of 4.2% compared with the previous year, but Zhejiang Province, in the rapid development of the industrial economy at the same time, there is a more serious carbon emissions and environmental pollution and other problems, for example, industrial wastewater emissions amounted to 102 million tonnes. In addition, in 2021, Zhejiang Province released ‘Zhejiang Province, ecological environmental protection “14th Five-Year Plan”, the plan clearly put forward “to 2025, Zhejiang basically built the first demonstration area of beautiful China,” the grand vision, so the scientific evaluation of the Therefore, it is of great significance to scientifically evaluate the efficiency of industrial green development of each prefecture-level city in Zhejiang Province under the background of ‘Dual-carbon’, and to explore more effective ways to promote industrial green development, which is of great significance to promote the green transformation of industry in Zhejiang Province.

2. LITERATURE REVIEW

The concept of green development first appeared in the Blue Book of Green Economy, put forward by the British environmental economist Pearce, the core is to emphasise the safety of the ecological environment [3], and Wang Lingling and Zhang Yanguo [4] believe that ‘green development’ is a new development model to achieve sustainable development through the protection of the ecological environment under the constraints of ecological and environmental capacity and resource carrying capacity. development under the constraints of ecological and environmental capacity and resource carrying capacity, and through the protection of ecological environment to achieve sustainable development. In the study of green development in the industrial field, Qu Congyi [5] believes that industrial green development is based on the extension of the concept of ‘green development’, which is a narrower concept of green development focusing on the industrial sector. The current research on industrial green development mainly focuses on the measurement of the level of industrial green development, the measurement of the efficiency of industrial green development, and the influencing factors.

In the research on the measurement of the level of industrial green development, Yuan Jianming [6] focused on the intensity of industrial development, resource consumption and environmental impact, government support in three aspects, the use of network analysis method ANP and entropy value method combined with the measurement of the degree of green development of industry in Anhui Province, Chu Zihui [7] used entropy weight-TOPSIS to assess the level of industrial green development of China's 30 provinces and municipalities, Lu Chenyu [8] used entropy weight-TOPSIS and spatial autocorrelation methods to combine to carry out spatio-temporal comprehensive measurement of China's industrial green development level.

In the research on industrial green development efficiency measurement, scholars mainly use the data envelopment analysis (DEA) method, in which Xu Sheng [9] et al. empirically measured and analysed the industrial total factor energy efficiency of 30 provinces in China using the DEA method, and found that there are large regional differences in China's inter-provincial industrial energy efficiency. Zhang Kai [10] et al. used the CCR model and the SBM model to measure the value of industrial green development efficiency in the eastern region under the desired output perspective and under the non-desired output perspective, and found that there are large differences in industrial green development efficiency among eastern provinces and cities, and Wang [11] used industrial three wastes as an input variable, and used Super-SBM to measure the provinces and municipalities in the Yangtze River Economic Belt in the period of 2007-2016 industrial green development efficiency, and concluded that the efficiency value in this region is generally low and the inter-provincial differences are significant.

In the study of influencing factors, scholars mainly focus on the level of economic development, industrial agglomeration, the level of technological research and development, the level of economic openness, environmental regulation and so on. For example, Yan Xiao [12] studied the impact of industrial agglomeration on the efficiency of industrial green development, and the results show that specialised agglomeration has a significant negative impact on industrial green efficiency, and the impact of diversified agglomeration on green efficiency is in the form of a positive U. Ke Liu [13] used geographically weighted regression to prove that technological innovation, government regulation and consumption level belong to the global range, while other drivers have little or no spatial heterogeneity. Ke Liu [13] and others used a geographically weighted regression to demonstrate that technological innovation, government regulation, and consumption levels are global in scope with little spatial heterogeneity, while the other drivers are urbanisation, industrial structure, economic development, and population density by their spatial scale.

In terms of research regions, most of the current domestic research focuses on the national level, central and western provinces and belt regions, with less coverage of the eastern provinces with developed industrial economies.

In summary, domestic research on industrial green development from different perspectives, but there are still shortcomings, first, few articles on the eastern economically developed provinces; second, when examining the efficiency of industrial green development, few articles include carbon dioxide emissions in the measurement system; third, few articles analyse the efficiency of industrial green development from a combination of static and dynamic; fourth, few articles use the global parametric DEA model for measurement. Therefore, this paper adopts the non-expected global super-efficiency SBM and GML index to measure the industrial green development efficiency in Zhejiang Province.

3. RESEARCH METHODOLOGY

3.1. Global Super-efficiency SBM Model

Therefore, this paper draws on the research of pastor [14] and Wang [15] to combine global parametric and super-efficiency SBM models to construct a global super-efficiency SBM model, which not only enables the evaluation of the efficiency of the inclusion of non-desired outputs as well as the further discussion of the decision-making unit with efficiency value of 1, but also enables the comparison to be carried out across periods. The specific steps are as follows: construct a set of environmental production possibilities based on the global parametric technique$EPPS^G$:

$$EPPS^G = \begin{cases} (x^t,\ y^t,\ z^t) | x_{km}^t \geq \sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t x_{km,}^t\, y_{kn}^t \leq \sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t y_{kn}^t \\ z_{kq}^t \geq \sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t z_{kq}^t,\ \ \lambda_k^t \geq 0 \end{cases} \tag{1}$$

Where k denotes the kth decision-making unit; t denotes the tth period; $x_m(m = 1,2 \cdots M)$ denotes the M input factors used by each DMU, $y_n(n = 1,2 \cdots N)$ denotes the kind of desired outputs of each DMU, and $z_q(q = 1,2 \cdots Q)$ denotes the kind of non-desired outputs of each DMU, the global parametric super-efficiency SBM formula is as follows:

$$\rho_{kt}^G = E(x^t,\ y^t,\ z^t) = min(1 - \frac{1}{M}\sum_{m=1}^{M}\frac{s_m^x}{x_{mk}})/\left[1 + \frac{1}{N+Q}(\sum_{n=1}^{N}\frac{s_n^y}{y_{nk}} + \sum_{q=1}^{Q}\frac{s_q^z}{z_{qk}}\right] \tag{2}$$

$$\text{st}\begin{cases} x_{mk} = \sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t x_{km}^t + s_m^x,\ \forall m(m = 1, 2 \cdots M) \\ y_{nk} = \sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t y_{kn}^t - s_n^y,\ \forall n(n = 1, 2 \cdots N) \\ z_{qk} = \sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t z_{kq}^t + s_q^z,\ \forall q(q = 1, 2 \cdots Q) \\ s_m^x,\ s_n^y,\ s_q^z,\ \lambda_k^t \geq 0 \\ \sum_{t=1}^{T}\sum_{k=1}^{K}\lambda_k^t = 1 \end{cases} \tag{3}$$

Where ρ_{kt}^G denotes the industrial green development efficiency value of the kth decision unit in period t under the global super-efficiency SBM, and the larger ρ_{kt}^G denotes the higher efficiency value; x_{mk}, y_{nk}, z_{qk}denotes the mth input factor value, the nth desired output value, and the qth non-desired output value of the kth decision unit, respectively; denotes the relaxation variables for the mth input factor, the nth desired output, and the qth non-desired output, respectively; and λ_k^t denotes the weights.

3.2. Global Malmquist-Luenberger Index

The super-efficient SBM model can statically measure the efficiency of green development of Zhejiang Province industry, while the Malmquist index can dynamically evaluate the efficiency, and this paper adopts the Malmquist-L index based on the global reference, i.e., the GML index, which overcomes the problems of both the traditional Malmquist index not being able to include the non-desired outputs as well as the fact that the Malmquist-L index does not necessarily exist. feasible solutions, where the specific GML index is as follows:

$$GML_k^{t,t+1}(x^t,\ y^t,\ z^t,\ x^{t+1},\ y^{t+1},\ z^{t+1}) = \frac{1+D^G(x^t,\ y^t,\ z^t)}{1+D^G(x^{t+1},\ y^{t+1},\ z^{t+1})} \tag{4}$$

Where$1 + \mathrm{D}^{\mathrm{G}}(\mathrm{x}^{\mathrm{t}},\ \mathrm{y}^{\mathrm{t}},\ \mathrm{z}^{\mathrm{t}})$ is the global directional distance function, which is solved using the above super-efficiency SBM. a GML index greater than 1 indicates that the value of industrial green development efficiency is increasing, a GML index equal to 1 indicates that it remains unchanged, and a GML index less than 1 indicates that it is decreasing. In addition, the GML index can be further decomposed into the technical efficiency change EC index and the technical progress change BPC index, where the formulas for the EC index and the BPC index are as follows:

$$EC_k^{t,t+1}(x^t,\ y^t,\ z^t,\ x^{t+1},\ y^{t+1},\ z^{t+1}) = \frac{1+D^G(x^t,\ y^t,\ z^t)}{1+D^G(x^{t+1},\ y^{t+1},\ z^{t+1})} \tag{5}$$

$$BPC_k^{t,t+1}(x^t,\ y^t,\ z^t,\ x^{t+1},\ y^{t+1},\ z^{t+1}) = \frac{1+D^G(x^t,\ y^t,\ z^t)}{1+D^G(x^{t+1},\ y^{t+1},\ z^{t+1})} \tag{6}$$

The EC index is greater than 1, which indicates that the technical efficiency change part of the industrial green development efficiency value is increasing, and the EC index is equal to 1, which indicates that the technical efficiency change part of the industrial green development efficiency value is unchanged, and less than 1 indicates a decrease. Similarly, the BPC index is greater than 1, which indicates that the change of technical progress in the value of industrial green development efficiency is increasing, and equal to 1 indicates that it is unchanged, and less than 1 indicates that it is decreasing.

4. CONSTRUCTION OF EVALUATION INDICATORS SYSTEM

Referring to the existing literature [16, 17], and following the principles of comparability, availability and scientificity of data, we mainly measure the efficiency of industrial green development from two levels of input and output. Among them, the input indicators were considered from the capital input, labour input, resource input, capital input in this paper with industrial net fixed assets, labour input for the average number of employees in industrial enterprises in each city, taking into account that industrial enterprises in Zhejiang Province accounted for a large proportion of electricity consumption, so the resource input using industrial electricity consumption, the output indicators are divided into the expected output and unexpected output, of which the expected output is the value added by the industry, and the unexpected output is industrial wastewater emissions, industrial sulphur dioxide emissions, industrial smoke (dust) emissions and industrial carbon dioxide emissions. The specific indicators are shown in Table 1:

Table 1. Evaluation Indicator System

Indicator type	Primary Indicators	Secondary Indicators
Input	Capital Input	Industrial net fixed assets
	Labor Input	The average number of employees in industrial enterprises
	Resource Input	Industrial electricity consumption
Output	Expected output	Industrial added value
	Unexpected output	Industrial wastewater emissions
		Industrial sulphur dioxide emissions
		Industrial smoke (dust) emissions
		Industrial carbon dioxide emissions

Among them, industrial carbon dioxide emissions are estimated by adopting the IPCC carbon emission inventory estimation method [18], with the following formula:

$$CE = \sum_n E(CO_2) = \sum_n M_n \times NCV_n \times CEF_n \times COF \times \frac{44}{12} \tag{7}$$

In the formula, CE represents the total industrial $\mathrm{CO_2}$ emissions, n represents different energy types, $\mathrm{E(CO_2)}$ represents the total industrial $\mathrm{CO_2}$ volume generated by each type of energy consumption, M_n represents the industrial consumption of each type of energy, NCV represents the net calorific value of each type of energy, CEF is the carbon emission factor per unit calorific value equivalent; COF is the carbon oxidation factor and the default value is set to 1; $\frac{44}{12}$ represents the conversion factor. In order to be comparable, this paper will take the intersection of the energy varieties of each city, in consideration of the legal application of data to the Bureau of Statistics selected the following energy categories of raw coal, gasoline, diesel and fuel oil.

Table 2. Type of energy

Type of energy	NCV (kJ/kg)	CEF (kgC/1million kJ)
raw coal	20908	25.8
gasoline	43070	18.9
diesel	42652	20.2
fuel oil	41816	21.1

Considering that when there are too many indicators, the valid conclusions derived from the DEA model may be difficult to interpret and understand, which will weaken the interpretability of the model, the entropy weight TOPSIS method was used to fit the non-desired output indicators into a composite index of industrial environmental pollution. The steps of entropy weight TOPSIS method are as follows:

First, in the comprehensive evaluation, in order to eliminate the influence of different units of measurement and inconsistencies in the type of each evaluation index, the data are first standardised to eliminate the differences in their scales.

$$X_{ij} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \tag{8}$$

Where i denotes the region and j denotes the indicator, and the data were then normalised:

$$P_{ij} = \frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}},\ i = 1, 2 \cdots \mathrm{n} \tag{9}$$

At this point, the relative information entropy of the indicator system is $e_i = -k \sum_{j=1}^{n}(P_{ij}\, ln\, P_{ij})$, $0 \leq e_{\mathrm{i}} \leq 1$, where $k = \frac{1}{ln\, n}$ and n is the value of the number of panel units. Then get the redundancy of the system $d_i = 1 - e_i$, which means the degree of dispersion or difference. Then get the entropy value:

$$W_i = \frac{d_i}{\sum_{j=1}^{n} d_i},\ i = 1, 2 \cdots \mathrm{m} \tag{10}$$

Immediately after that we construct the normalised weighted evaluation matrix:

$$R = \{r_{ij}\}_{n \times m} \tag{11}$$

The optimal and worst solutions are obtained in the normalised weighted evaluation matrix:

$$R^{+} = (r_{max1},\ r_{max2} \cdots r_{maxm}) \tag{12}$$

$$R^{-} = (r_{min1},\ r_{min2} \cdots r_{minm}) \tag{13}$$

Where r_{maxm} and r_{minm} are the maximum and minimum values of the mth row of the normalised weighted evaluation matrix, and then using the Euclidean distance formula, the distances from the evaluation indexes to the optimal and the worst solutions are obtained for different regions:

$$D_i^{+} = \sqrt{\sum_{j=1}^{m}\left(r_{max} - r_{ij}\right)^2} \tag{14}$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{m}\left(r_{min} - r_{ij}\right)^2} \tag{15}$$

Finally, the composite evaluation value is calculated to obtain C_i^{+}:

$$C_i^{+} = \frac{D_i^{-}}{D_i^{+} - D_i^{-}} \tag{16}$$

This paper selects the data of 11 prefecture-level cities in Zhejiang Province from 2011 to 2020, the main sources of data are China Urban Statistical Yearbook, Zhejiang Provincial Statistical Yearbook and the statistical yearbooks and statistical bulletins of each prefecture-level city, and individual missing data are made up by linear interpolation.

5. ANALYSIS OF EMPIRICAL RESULTS

5.1. Static Measurement of Green Development Efficiency in Zhejiang Province Industry

This paper uses MATLAB software to measure the efficiency of industrial green development in Zhejiang Province from 2011 to 2020, and the results are shown in the following table:

Table 3. Efficiency of industrial green development in cities of Zhejiang Province

Year City	Hangzhou	Ningbo	Wenzhou	Jiaxing	Huzhou	Shaoxing	Jinhua	Quzhou	Zhoushan	Taizhou	Lishui	mean value
2011	0.40	0.33	0.33	0.25	0.36	0.40	0.29	0.28	0.33	0.28	0.33	0.32
2012	0.40	0.34	0.30	0.25	0.53	0.55	0.29	0.28	0.35	0.28	0.35	0.36
2013	0.28	0.21	0.30	0.14	0.19	0.19	0.22	0.21	0.27	0.24	0.21	0.22
2014	0.41	0.38	0.51	0.29	0.42	0.70	0.33	0.30	0.54	0.30	0.68	0.44
2015	0.42	0.43	0.59	0.31	0.44	1.01	0.31	0.29	0.57	0.27	0.37	0.46
2016	0.44	0.41	1.01	0.30	0.42	1.01	0.33	0.31	1.13	0.28	0.40	0.55
2017	0.58	0.68	0.35	0.39	0.40	0.43	0.30	0.32	0.29	0.29	0.30	0.40
2018	0.75	0.68	0.38	0.48	0.47	0.52	0.36	0.37	0.24	0.31	0.32	0.44
2019	1.07	0.85	0.47	0.40	0.39	0.41	0.32	0.35	0.27	0.27	0.33	0.47
2020	1.08	0.85	1.00	0.63	0.57	0.59	0.03	0.45	1.15	1.14	0.65	0.74
mean value	0.58	0.52	0.52	0.34	0.42	0.58	0.28	0.32	0.51	0.37	0.40	0.44

From the data in Table 3, over the past ten years, the efficiency value of industrial green development in some cities in Zhejiang Province has been in a gradual incremental state, except for a decreasing trend in the industrial green development efficiency value during the period of 2012-2013 and 2016-2017. Among the 11 prefecture-level cities, the minimum value is 0.025 and the maximum value is 1.138, with a large gap between regions. Among them, the industrial green development efficiency value of Hangzhou City exceeds 1 in 2019 and 2020 and reaches DEA effective, the industrial green development efficiency value of Wenzhou City exceeds 1 in 2016 and 2020 and reaches DEA effective, the industrial green development efficiency value of Shaoxing City also reaches DEA effective in 2015 and 2016, and the 2016 and 2015 industrial green development efficiency value is 1.13 and 1.15, reference [19], the efficiency value is divided into four stages: for the efficiency ineffective stage; for the efficiency medium stage; for the efficiency good stage; for the efficiency optimal stage; for the super-efficiency stage, in the period of 2011-2019, the industrial green development efficiency value of each prefectural-level city of Zhejiang Province is in the middle of the lower level, which indicates that environmental protection and resource transformation efficiency still has more room for improvement.

5.2. Dynamic Analysis of Industrial Green Development Efficiency in Zhejiang Province

The dynamic analysis of the industrial green development efficiency of each city in Zhejiang Province using the GML index was carried out, and the results are as follows:

As shown in Table 4, the average value of the GML index of industrial green development in Zhejiang Province from 2012 to 2020 is 1.21, indicating that overall the efficiency of industrial green development is improving in this period, and among the GML indexes of the prefectural-level cities, except for Jinhua City, which is declining, the other cities are all greater than 1, indicating that overall the efficiency of industrial green development in these cities is improving, among which the fastest improvement is Zhoushan City, which reaches 1.48, followed by Taizhou City. The fastest improvement is Zhoushan City, reaching 1.48, followed by Taizhou City. Combined with the decomposition of the GML index, the EC value of technical efficiency change in two cities, Huzhou and Taizhou, is greater than the BPC value of technical progress change, indicating that the improvement of industrial green development efficiency mainly relies on the progress of technical efficiency, and the EC value of technical efficiency change in the other nine cities is smaller than the

BPC value of technical progress change, indicating that the improvement of industrial green development efficiency in the other cities mainly relies on the technical progress.

Table 4. GML index value of cities in Zhejiang Province

City	GML index value	EC value	BPC value
Hangzhou	1.14	1.06	1.22
Ningbo	1.17	1.05	1.15
Wenzhou	1.26	1.16	1.33
Jiaxing	1.19	1.10	1.17
Huzhou	1.16	1.09	1.07
Shaoxing	1.30	0.97	1.23
Jinhua	0.92	0.94	1.19
Quzhou	1.07	1.03	1.08
Zhoushan	1.48	1.02	1.44
Taizhou	1.35	1.19	1.11
Lishui	1.26	1.08	1.23
mean value	1.21	1.06	1.20

6. CONCLUSIONS

This paper analyses the industrial green development efficiency of Zhejiang Province by the global reference super-efficiency SBM model and the GML index decomposition method, and in general, the industrial green development efficiency of Zhejiang Province municipalities is at a low level and has not reached the DEA effective state. Specifically, in the examination period, Hangzhou and Shaoxing have the highest average industrial green development efficiency, reaching 0.58, and the lowest is Jiaxing, with an industrial green development efficiency value of only 0.34. Through the decomposition of the GML index, we find that except for Jinhua, the GML index of the rest of the cities are all greater than 1, and Zhoushan City has the highest GML index, reaching 1.48, so we can illustrate that in general Therefore, we can show that in general, the industrial environmental protection efficiency of each city is improving.

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