Research Methods and Application of Ecological Efficiency

Han Weihong, Yang Xinjiletu, Zhang Bing[*], Yang Yanli

School of Economics and Management, Inner Mongol University of Technology, Hohhot City, China

Email address:

bill@imut.edu.cn (Han Weihong), 1257664153@qq.com (Yang Xinjiletu), ZB13253526775@163.com (Zhang Bing),
1991989418@qq.com (Yang Yanli)
[*]Corresponding author

Abstract: In recent years, the frequent occurrence of extreme weather is a global problem facing all countries. With the excessive consumption of energy and the massive emission of carbon dioxide represented by energy-intensive industries, it has caused serious negative impacts on social and economic development and ecological environment, and it has caused serious negative impacts on social and economic development and ecological environment. Therefore, it is very important to deal with the relationship among economic development, resource input and ecological environment. Eco-efficiency is an important tool for quantitative analysis of the ratio between economic output and resource input, which is closely related to the sustainable development of economy, environment and resources. By reviewing domestic and foreign literature, this paper summarizes the concept, evaluation method and application of ecological efficiency, and concludes that (1) The core concept of ecological efficiency is to obtain more economic benefits with less resource input; (2) Evaluation methods of ecological efficiency: Mainly include data envelopment analysis (DEA), index evaluation method, ecological footprint method, single ratio method and SBM method in the measurement of ecological efficiency, among which DEA model is widely used; (3) The application of eco-efficiency mainly involves enterprises, industries and regions, among which there are few researches on enterprise eco-efficiency.

Keywords: Ecological Efficiency, Environmental Benefits, Economic Benefit

1. Introduction

Since the reform and opening up, China's economy has continued to grow rapidly, resulting in excessive energy consumption and large amounts of carbon dioxide emissions, which have caused serious environmental pollution and seriously threatened people's lives and property safety. According to statistics, by 2020, China's carbon dioxide emissions will reach 9.899 billion tons, accounting for 30.66% of the global total. At the same time, China's carbon dioxide emissions are increasing every year, ranking first in the world [1]. Thus it can be seen that the ecological environment on which human beings live has suffered serious damage. In this case, environmental pollution will not only reduce the quality of economic development, but also become a bottleneck restricting the sustainable development of society. Therefore, it is very important to deal with the relationship among energy consumption, economic growth and ecological environment, which has become the research focus of scholars at home and abroad. Ecological efficiency is the basis of sustainable development theory and reflects the relationship between economic growth and ecological environment. In recent years, with the deepening of ecological civilization construction, it has promoted the process of ecological efficiency research of various industries, to realize the sustainable development of social economy has important theoretical and practical significance.

By combing and analyzing the existing literature, this paper summarizes and evaluates the concept and connotation, research methods and applications of eco-efficiency, which are focused on by relevant researches at home and abroad, so as to provide references for the study of eco-efficiency.

2. The Concept of Eco-efficiency

The term "ecological efficiency" was proposed by German

economists Schaltegger and Sturn in 1990, and ecological efficiency was defined as the ratio of incremental value of products (or services) to incremental environmental impact. Subsequently, the Organization for Economic Cooperation and Development (OECD 1998) and Li Liping (2000) defined ecological efficiency as a measure of input-output ratio relationship, and proposed that social output should be maximized under the condition of minimizing resource and energy consumption [2]. Later, some scholars further expanded this concept. Lv Bin (2006) pointed out that ecological efficiency should be expressed in terms of resource input and environmental impact [3]; Gan Yonghui (2008) established a sound evaluation system and believed that ecological efficiency was the ratio of resource input to economic and environmental impacts [4]. With the deepening and expansion of the research on ecological efficiency, domestic scholars also put forward other related concepts such as green efficiency, low carbon efficiency and environmental efficiency.

In general, the idea of ecological efficiency is to measure the ratio of resource input to economic and environmental benefits generated in the production process of a country (region) in a certain period of time, so as to obtain more economic value with less resource input, and combine the theory of ecological efficiency with the sustainable and coordinated development of energy, economy and environment.

3. Evaluation Method of Ecological Efficiency

Domestic and foreign scholars have conducted researches on the evaluation of ecological efficiency, including two aspects: the measurement and influencing factors of ecological efficiency. The main research methods used for the measurement of ecological efficiency include data envelopment analysis (DEA), index evaluation method, ecological footprint method, single ratio method and SBM method, among which DEA model has been widely used in recent years. Xue Xuandeng (2020), Wang Junling (2022) and Zhang (2023) respectively calculated the ecological efficiency of agriculture, iron and steel industry and logistics industry by using DEA model [5-7]. Later, with the expansion of DEA model, Zhai Danni (2022) constructed the input-output index of ecological efficiency, and used the super-efficiency DEA model to calculate the industrial ecological efficiency of various regions in East China from 2012 to 2017 [8]; Xie Yali (2020) calculated the ecological efficiency of 26 districts and counties in the Three Gorges Reservoir area by using the super-efficiency DEA model. The research showed that the ecological efficiency in the Three Gorges Reservoir area was improved to a certain extent, but the overall level was low [9]; When Moutinho et al. (2017) evaluated the ecological efficiency of 26 European countries, the input indicators were labor efficiency, capital productivity, fossil energy consumption and renewable

energy consumption, and the output indicator was the proportion of greenhouse gas emissions in GDP [10]; In addition, Liu Jun (2019) calculated the eco-efficiency value of tourism in different regions of China by using the single ratio method, and then compared each eco-efficiency value [11]; Lv Zhouyang (2022) calculated the mean energy eco-efficiency of each city from 2009 to 2019 based on the SBM model of unexpected output [12]. DEA model is widely used because it is more comprehensive in selecting indexes and can effectively measure ecological efficiency.

Secondly, with regard to the influencing factors of eco-efficiency, Li Ying (2023) further tested the influencing factors of agricultural eco-efficiency in Anhui province by using factor detector [13]; Chen Yang (2022) adopted the panel fixed effect model to analyze the influencing facto rs of agricultural eco-efficiency in China, as well as the significance of urbanization level, financial support for agriculture and agricultural mechanization level [14]. However, the most commonly used method is Tobit regression model. Sun Zhenqing (2021), Shi Tiange (2023) and Zhang Siying (2022) all adopt Tobit regression model to analyze influencing factors of ecological efficiency to solve the problem of limited dependent variables [15-17].

4. The Application of Eco-efficiency

As a bridge connecting economy, environment and resources, ecological efficiency is a comprehensive index to measure economic development and social sustainable development. Therefore, research on ecological efficiency is widely applied in enterprises, industries and regions. For enterprises, they focus on marginal cost and energy consumption efficiency of carbon emission reduction. For industry, the industry pays more attention to the output brought by the unit input; for the region, focus on sustainable economic development.

From the perspective of enterprises, domestic and foreign scholars have little research on enterprise eco-efficiency evaluation. The main reason is that it is difficult to obtain relevant enterprise data. Elisenda (2018) studied the eco-efficiency of 11,336 smes in 28 European countries, and the empirical results showed that not all eco-efficiency was positively correlated with enterprise performance [18]. Feng Junhua (2020) built an ecological efficiency evaluation index system based on the panel data of industrial enterprises in 16 heavily polluting industries from 2006 to 2017, and found that the impact of enterprise capital input, enterprise scale, environmental regulation intensity and government support on the ecological efficiency of heavily polluting enterprises was significantly positive [19]; Xia Yongqiu (2019) selected six typical listed coal enterprises and measured the ecological efficiency of these enterprises through the DEA-Malmquist model, and the results showed that the ecological efficiency of these six coal enterprises showed a trend of first decline and then increase [20]; Chen Yihui (2018) made research on the relevant data of common industrial enterprises in Fujian, and the research results showed that the ecological efficiency

of industrial enterprises had certain temporal characteristics and spatial distribution characteristics. On the whole, the ecological efficiency was on the rise year by year, and population density, per capita GDP, proportion of industrial output value, and utilization rate of industrial solid waste had a positive impact on the ecological efficiency of industrial enterprises [21].

From the perspective of industry, most researches on eco-efficiency focus on agriculture, industry, tourism and other industries. Liu Zhixiong (2022), Yang Xinlei (2022) et al. studied agricultural eco-efficiency and found that the overall level of agricultural eco-efficiency was on the rise [22, 23], Huang Heping (2020) analyzed the ecological efficiency of agricultural land in Jiangxi Province, and the research results showed that the ecological efficiency of agricultural land in Jiangxi Province decreased first and then increased during the study period, regardless of whether the undesirable output was considered [24]; Lang Xuan (2023) used the Super-SBM model to study the influencing factors of industrial eco-efficiency in 12 western provinces of China. She found that economic development level, industrial agglomeration and opening to the outside world significantly promoted industrial eco-efficiency in western regions, while environmental regulation and urbanization level had obvious inhibition [25]; Yang Chen (2020) calculated the industrial ecological efficiency of 31 provinces in China, and the research results showed that the industrial ecological efficiency was not effective [26]; Tian Hong (2022) took Shandong Province as an example to conduct a quantitative analysis and evaluation on the tourism eco-efficiency of prefecture-level cities, and the results showed that the tourism eco-efficiency of Shandong Province was at a relatively high level, with an overall trend of fluctuation and rise [27]. In general, the measurement of ecological efficiency involves the input and output of resources, and the impact of resources and environment on agriculture, industry and tourism is crucial.

From the perspective of region, the study of eco-efficiency involves countries, city clusters, provinces, cities and counties, etc. Chen Yang (2022) and Borisovna (2022) respectively studied the eco-efficiency of China and 17 European countries [1, 28]; Zhang (2023), Shi Tiange (2023) and Zhang Qiufeng (2022) respectively studied the ecological effectiveness of the Beijing-Tianjin-Hebei region, the eastern coastal urban agglomeration of China and the five major urban agglomerations in China [7, 16, 29]. Deng Fan-fan (2022) measured the overall regional ecological efficiency of prefecture-level cities in Hubei Province during 201-2018 by using the super-efficiency SBM and Malmquist index model, and the results showed that the regional ecological efficiency of Hubei Province was on the rise during 2011-2018 [30]; Xu Weixiang (2022) measured the urban ecological efficiency in the Yellow River Basin from the perspective of undesired output, and found that the urban ecological efficiency in the Yellow River Basin showed a steady rise, but the whole-area and resource-based cities showed a certain gradient effect, with polarization [31];

Zhang Zhan (2022), based on the agricultural panel data of the county administrative units in Hunan Province, adopted the spatial correlation analysis method and found that there were significant differences in agricultural eco-efficiency among different regions, but the eco-efficiency showed a rising trend in fluctuations [32]. Zong et al. (2023) took Qin 'an County in the loess hilly region of central Gansu as an example and based on panel statistics of 17 townships from 2001 to 2020, the results showed that the deagricultural level of labor force promoted agro-ecological efficiency through direct effects rather than spatial spillover effects [33].

5. Conclusion

Through the elaboration of the definition and development history of ecological efficiency, it can be considered that ecological efficiency is a ratio of input and output, while considering the combination of economic and environmental benefits. Its core idea is to minimize the input of resources and environment, maximize the output of economic benefits, and realize the optimal allocation of resource utilization efficiency and the level of social sustainable development.

In terms of the research methods of ecological efficiency, there are mainly data envelopment analysis (DEA), index evaluation method, ecological footprint method, single ratio method and SBM method to measure ecological efficiency and analyze the influencing factors. However, data enveloping analysis (DEA) is widely used at present. This model can take the influencing factors into account, retain the original data information, and add non-expected output indicators to better measure and evaluate the ecological efficiency.

The application of eco-efficiency involves enterprises, industries and regions. At the micro level, there are few researches on enterprise eco-efficiency, which is due to the confidentiality of enterprise data and difficult to obtain. At the mesolevel, the research on industrial eco-efficiency is mainly concentrated in agriculture, industry, tourism and other industries. The development of agriculture has high requirements on environmental resources. The development of industry needs to consume energy and factor input; As a tertiary industry, tourism is based on natural environment and resources. Therefore, a large number of domestic and foreign scholars have studied ecological efficiency from the perspectives of agriculture, industry and tourism. At the macro level, a country, city group, province or county region with certain characteristics is studied.

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