International Journal of Economics, Finance and Management Sciences
2023; 11(2): 76-81
http://www.sciencepublishinggroup.com/j/ijefm
doi: 10.11648/j.ijefm.20231102.15
ISSN: 2326-9553 (Print); ISSN: 2326-9561 (Online)

Evaluation and Approach of Industrial Green Development: A Literature Review

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To cite this article:

Yang Xinjiltu, Zi Chunhao, Han Weihong, Yang Yanli. Evaluation and Approach of Industrial Green Development: A Literature Review. *International Journal of Economics, Finance and Management Sciences*. Vol. 11, No. 2, 2023, pp. 76-81. doi: 10.11648/j.ijefm.20231102.15

Received: March 29, 2023; **Accepted**: April 25, 2023; **Published**: April 27, 2023

Abstract: With the increasing consumption of natural resources and the aggravation of environmental pollution, human beings began to realize that in order to realize the sustainable development of society, we must further examine the relationship between economic development and natural environment. In particular, it is generally believed that human activities have had a negative impact on global climate in the past hundred years, making the global warming trend increasingly obvious. If mankind wants to ease the contradiction between himself and the natural environment, we must go from the opposite to the integration of nature. Industrial green development is an attempt to integrate industrial economic operation system with natural system in order to achieve a balance. Green industry is a necessary driving force to promote green economic development and an important way to achieve ecological civilization. In order to further understand the related research of industrial greening, a new research direction is sought. Based on the summary of relevant literature, this paper firstly discusses the connotation and definition of industrial greening. Secondly, it is pointed out that ecological efficiency is an important basis for evaluating the degree of industrial green development, and the research on ecological efficiency mainly includes three aspects: theoretical interpretation, calculation and driver identification. Then, it summarizes the related ideas of industrial green path, including advanced technology application, material reduction, life cycle evaluation, green design, establishment of ecological industrial parks, etc. Finally, it points out the shortcomings of existing research and the prospects for future research.

Keywords: Sustainable Development, Industrial Green Development, Ecological Efficiency, Industrial Green Path

1. Introduction

With the development of human civilization, human society has gone through three stages: primitive society civilization, agricultural civilization and industrial society civilization. Although a series of great achievements have been made in this process, the depletion of natural resources and the pollution of ecological environment have become more and more serious, and the contradiction between human beings and nature seems to have reached an irreconcilable point. In order to arouse people's re-understanding and reflection on their own existence, Rachel Carson's book Silent Spring in the 1860s revealed the harm of chemicals to nature and human beings themselves, and warned people not to drink poison to quenched thirst. In order to realize the sustainable existence of society, human beings must re-examine their own ideas and economic operation mode. The chairman Xi Jinping pointed out in his keynote speech at the 15th Summit of the Conference of the Parties to the Convention on Biological Diversity that ecological civilization is the historical trend of the development of human civilization. Ecological civilization requires human economy and natural environment to achieve dynamic balance and coordinated development, and industrial green development (ecological) is an important way to achieve this goal [1]. This paper reviews the relevant literature at home and abroad from the aspects of connotation, evaluation and approach of industrial green development.

2. Connotation of Industrial Green Development

Industrial green development is essentially the expansion of the greenization theory in the industrial level. Different

scholars have different concerns on the understanding of the connotation of industrial green development. Frosch, R. A. proposed that industrial greening is a revolution in which human beings hold a "terminal governance" attitude towards environmental problems caused by previous industrial operations, that is, they no longer regard the industrial system as an independent unit, but regard the human industrial system and the natural environmental system as a whole [2]. In the opinion of ERKMAN S, industrial green development puts forward a new idea, that is, industrial system can be regarded as a specific ecosystem, because both industrial system and natural ecosystem can be described as the flow of material, energy and information [3]. Martin Janicke believe that the "green transformation" of industry is essentially an instrumental strategy to prevent crisis, and the green growth brought by green transformation cannot bring high GDP growth, but can only achieve moderate growth [4]. Zhong Maochu believed in that industrial green development is actually a compromise between human economic development and the carrying capacity of natural environment, and any measure to expand the economic scale will inevitably have a negative impact on the environment, and theoretically proved that economic development and natural environmental protection cannot achieve a "win-win situation" in the general sense [1]. Luo Ling et al. theoretically proposed that industrial structure optimization, which guarantees the increase of industrial output when the ecological environment quality is fixed and realizes the improvement of ecological environment quality when the output of industrial products is unchanged, can achieve a "win-win situation" between industrial economic growth and ecological environmental protection. It also mentions the practical evidence of "win-win" between industrial economic growth and ecological environment, that is, China's ecological environment has been improved while the total amount of industry has increased in recent years [5]. Gu Shuzhong proposed ecological industry refers to the process or behavior of industrial ecologicalization and greening, which refers to resource reduction, environmental pollution reduction and ecological reduction [6]. BAUMANN H et al. believed that the focus of ecological industry should not only focus on material flow, but also pay more attention to the relationship between human behavior and material flow. They proposed "social material flow method" and analyzed the case of bakery [7]. This study takes into account the influence of social factors on ecological industry and points out a new direction for ecological industry research. Although there is no unified definition of industrial green development (ecological), it is generally believed that industrial greening is a trade-off between economic output and environmental protection.

3. Evaluation of Industrial Green Development

3.1. Connotation of Industrial Ecological Efficiency

Industrial ecological efficiency is an important measure of the degree of industrial greenness, which is fundamentally reflected in the improvement of industrial ecological efficiency [1]. The World Business Council for Sustainable Development (WBCSD) first mentioned the complete concept of eco-efficiency in 1992, that is, "Eco-efficiency means the gradual reduction of the negative impact on the environment and the intensity of resource extraction throughout the life cycle, the upper limit of the negative impact and the intensity of extraction is at least consistent with the estimated carrying capacity of the Earth's environment. To provide competitively priced goods and services that meet human needs and bring about a high quality of life ". The Organization for Economic Cooperation and Development (OECD) regards ecological efficiency as an input-output process, that is, higher economic output is obtained while lower environmental protection cost and natural resources are input. Jollands et al. pointed out that eco-efficiency evaluation has become a necessary response measure for management departments to waste problems in the current production process, and it is one of the most analytical and quantitative methods for enterprises interested in practical methods to obtain sustainable development [8]. The eco-efficiency is a method to evaluate the parameters of sustainable development in order to reduce resource consumption and environmental pollution while maintaining or improving the value of manufactured products [9, 10]. Zeng Zhi et al. proposed that ecological efficiency describes the balanced relationship between resource and environmental input and economic development [11]. To sum up, industrial ecological efficiency is the extension of the concept of ecological efficiency at the industrial level, which requires the maximum ratio of the added value of industrial economic output to that of resource consumption and environmental pollution.

3.2. Industrial Ecological Efficiency Measurement

From the measurement field of ecological efficiency, domestic and foreign scholars have extended the measurement research to every specific corner. Liuguo Shao et al. used two-stage DEA (data envelopment analysis) to evaluate the ecological efficiency of China's industrial sector from 2007 to 2015 [12]. Xiuli Liu et al. evaluated the ecological efficiency of circular economy system in the largest mining area of Shanxi Province, China based on emergy theory and DEA method [13]. Lin Yang et al. used the revised ecological footprint model to evaluate the ecological efficiency of China from 1978 to 2016 [14]. Wanqiu Hu et al. used the relaxed DEA model to evaluate the ecological efficiency of a centralized sewage treatment plant in an industrial park [15]. Benedetta Coluccia et al. used DEA model to estimate the ecological efficiency of Italian agriculture [16]. Chen Yang et al. used the superefficiency DEA-SBM model and DEA-Malmquist index method to evaluate the agricultural eco-efficiency in China and analyze the change trend of its value in previous years [17]. Zhang Rui et al. used DEA model to measure the energy eco-efficiency of logistics industry in 30 provinces and cities in China from 2005 to 2019 [18]. Lu Fei et al. used the non-expected relaxation DEA model to

measure the tourism eco-efficiency of 30 provinces from 2006 to 2016 [19]. Jia Fengrui et al. established the material flow model of metal copper resources by using the material flow analysis method, constructed the copper resource ecological efficiency evaluation system through hierarchical analysis and entropy weight method, and evaluated the ecological efficiency of copper resources in China from 1990, 1995 and 2000 to 2015 [20]. Cui Wang et al. use emergy method to evaluate eco-efficiency of logistics parks [21]. Through a large number of searches and references, there are generally more articles on the analysis and calculation of ecological efficiency in the primary and secondary industries and regions in the industry, while fewer studies on the ecological efficiency in the tertiary industry and enterprises, and most of the methods used are DEA models.

3.3. Identification of Driving Factors of Industrial Ecological Efficiency

Shenggang Ren et al. used the STIRPAT model to prove that environmental regulation has a certain promoting effect on ecological efficiency, and the effects of different environmental regulations are significantly different in different regions [22]. Yu Shaochen et al. constructed a spatial Dubin model, analyzed the factors driving the ecological evolution of logistics industry, and proposed that economic development level, industrial structure, government regulation, environmental regulation and technological innovation play an obvious positive role in promoting the ecological evolution of logistics industry [23]. Zheng Linan et al. used grey correlation analysis to explore the main driving factors of temporal and spatial evolution of agricultural eco-efficiency in China, and found that agricultural eco-efficiency was mainly affected by eight types of factors, such as farmland ownership determination, financial support for agriculture, agricultural production capacity, agricultural machinery density, agricultural scale level, agricultural disaster rate, industrialization level and urbanization level [24]. Deng Zongbing et al. tested the source of industrial eco-efficiency loss and external influencing factors from two dimensions of inefficiency and external environment, and found that economic level, environmental regulation and industrial agglomeration promoted the improvement of industrial eco-efficiency in China, while energy structure and foreign investment inhibited it [25]. Through the effective identification of the driving factors of industrial ecological efficiency, it is helpful to find out the direction of industrial green development, which has important strategic significance.

4. Industrial Greening Approach

In order to promote the process of industrial green development, scholars at home and abroad have theoretically discussed the ways of greening from different angles in recent years, including the application of advanced technology, material reduction, life cycle evaluation, green design, the establishment of ecological industrial parks, etc.

4.1. Advanced Technology Application

At The Future of Artificial Intelligence in the Context of Industrial Ecology Conference held in 2021, many experts proposed that the application of artificial intelligence and digital technology will help promote the development of green industry. Four suggestions are specifically proposed to establish a committee or working group to study the application of artificial intelligence technology in industrial clusters, to make efforts in interdisciplinary integration, to provide optimal artificial infrastructure and configuration for industrial ecology to minimize environmental pollution, and to enhance the effectiveness and cohesion of available data [26]. Dai Xiang et al. theoretically proved that digital empowerment can effectively promote the green transformation of manufacturing enterprises [27]. The use of advanced technology can fundamentally promote the greening of industries, because technology directly determines the production and recycling process and the final form of products.

4.2. Material Reduction

The background of "material reduction" is that the rapid economic growth is highly dependent on raw materials and energy, which is often accompanied by the huge consumption of natural resources and the discharge of a large amount of waste [28]. Labys Waddell et al. believe that material reduction is a process in which high-tech environmental protection materials and clean energy replace mineral resources with high energy consumption and high pollution, and technology is the main driving factor of material reduction [29]. Bernardini Galli et al. believed that material reduction refers to the reduction in the utilization of natural raw materials in economic activities [30]. The main purpose of material reduction is to reduce the intensity of material resource consumption in industrial system. However, KASULAITIS et al. found that when focusing on a specific electronic product, material reduction could not bring about a reduction in the net use of materials, which is due to the complex interaction between consumer electronic products and the increasing consumption [31].

4.3. Life Cycle Evaluation

Life Cycle Assessment (LCA) refers to the quantitative summary and evaluation of the input, output and potential environmental impact of a product system in the whole life cycle chain from production, consumption to recycling. Ignacio Zabalza Bribian et al. analyzed the impact of construction activities on the environment during the whole cycle by using the life cycle assessment method, and proved from the perspective of ecological efficiency that the use of advanced technologies, waste recycling and ecological innovation of material factories can greatly reduce the damage of construction activities on the natural environment [32]. Jia Zhijie et al. discussed the life cycle evaluation of lithium iron phosphate batteries in different application scenarios [33].

4.4. Green design

Green design can also be called environmentally friendly design, which means that in the initial stage of product process design, the impact of product production, consumption and recycling process on the environment is fully taken into account, so as to reduce environmental pollution. L. W. Jelinski et al. proposed that the ecologicalization of manufacturing industry could start from the material flow analysis of raw materials or the design of raw materials of products [34]. Chen Yanqing et al. pointed out that the design of express packaging presents a trend of reduction, intelligence and humanization, and the design and use of packaging that is pollution-free to the ecological environment, conducive to resource saving and harmless to humans can promote sustainable development [35]. However, HAUSCHILD et al. proposed that green design is sometimes the second-best choice from the environmental perspective, because product process design is carried out on the basis of the existing tool level restrictions and limited raw material selection [36].

4.5. Establish Industrial Ecological Parks

In 2021, the United Nations Industrial Development Organization gave a brief definition of industrial eco-park: Industrial eco-park is an area that implements centralized management of industrial activities, which can strengthen the links between industrial activities and groups, so as to achieve common benefits in economic, social and environmental performance. In essence, industrial ecological park is the micro imitation and experiment of ecosystem for the requirement of sustainability. The theoretical model of industrial ecological park established by Liwarska-Bizukojc et al. includes four elements: the structure of ecosystem; Ecosystems (in which firms are divided into producers, consumers and decomposers); Mass flow and energy flow; Interaction type [37]. GIBBS et al. believes that the establishment of industrial ecological parks can promote the greening and sustainability of industries, but there are still many problems in practice, and emphasizes the necessity of government policy support [38]. Zhen Jie proposed to strengthen the ecological civilization construction of industrial parks in the Yellow River Basin by making full use of the preferential policies of the state to support the development of the central and western regions, strengthening multi-level cooperation based on industrial parks, and promoting the intelligent transformation and upgrading of leading industries in the parks [39].

5. Conclusion

To sum up, the main characteristics of industrial green development are as follows. Firstly, it has dual goals, which is to balance social economy and natural ecology in essence. Secondly, it has obvious interdisciplinary characteristics. The natural ecological theory is applied to the economic system and the corresponding transformation of the production system is carried out. Thirdly, imitate the natural ecosystem to realize the inner cycle of industrial economy and the outer cycle of docking with the natural environment, so as to promote the integration of the social economic system and the natural ecosystem. The important measure of industrial greening is ecological efficiency, and there are two ways to promote ecological efficiency, namely internal innovation and external promotion. Internal innovation includes industrial restructuring or improvement, introduction of high and new technology and implementation of advanced management methods. External impetus includes policy drive, culture drive and market drive. Domestic and foreign scholars have conducted a lot of research on industrial greening and ecological efficiency, but there is no complete theoretical system of industrial greening development at present, the interaction mechanism between economic production and natural ecology is not clear, quantitative research is less than qualitative research, these aspects need to be strengthened.

Acknowledgements

This paper is supported by a project of National Natural Science Foundation of China (Project No.: 71864027): Improvement of CGE model randomization and optimization of applicable tax on water pollutants from the perspective of water environment carrying capacity; Project of National Natural Science Foundation of China: Impact Path of Carbon trading Mechanism on Eco-efficiency of Energy-intensive Industries and spatial-temporal Simulation Evaluation (Project No.: 72263025); The Humanities and Social Sciences Research Project of Ministry of Education: Research on the Optimization mechanism of Regional Quota Tax Rate of Environmental Protection Tax: Based on the General Equilibrium Analysis of Environmental Self-purification ability and Economic Activities (Project No.: 19YJA790023); Inner Mongolia Natural Science Foundation Project: One of the phased achievements of the Research on the Evaluation mechanism and Uncertainty of dust Disaster economic loss based on stochastic CGE Model (Project No.: 2020LH07001).

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