Bibliometrics Analysis of Ecological Efficiency Research

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Abstract: Based on 649 journal papers on ecological efficiency from the Web of Science, this paper uses bibliometrics methods to analyze the research trends and hotspots in the field of ecological efficiency from the external features and content characteristics of existing literature. The research shows that the study of ecological efficiency is in the stage of rapid growth; the evaluation methods of ecological efficiency, the combination with life cycle assessment theory, the combination with industrial ecology and the agricultural ecological efficiency are hot topics. This paper quantitatively summarizes and refines the core research topics of ecological efficiency, which has important reference value for the future research of ecological efficiency.

1. Introduction

Eco-efficiency refers to the efficiency in the process of using ecological resource to meet human needs, that is, to get more value output with less resources input, and to establish an optimal link between the maximum economic objectives and the optimal environmental objectives. Ecological efficiency is an important method to measure the level of ecological civilization. How to measure and improve ecological efficiency have become key directions of ecological research. In recent years, many scholars have sorted out relevant papers on ecological efficiency from different perspectives, which provide important reference for scholars to understand the research progress. But the current review is based on the qualitative analysis of small samples. Based on the quantitative analysis of large samples, this paper summarizes relevant literature on ecological efficiency from the perspective of comparing the researches at home and abroad, analyzing the current research trends and hot spots, and predicting the development direction in the future, which are of great significance to promote the study of ecological efficiency.

2. Analysis of the External Characteristics of the Literature on Ecological Efficiency

The samples of this study come from the Web of Science. The search condition is SCI or SSCI paper which has “ecological efficiency“ or “eco-efficiency“ in “TS“. The paper should be published before August 27, 2018. A total of 1267 papers have been retrieved. Through manual identification and elimination of unrelated documents, the final sample number is 649.

2.1 Quantity of relevant literature

The change of the number of papers directly reflects the growth of scientific knowledge in this field. The number of papers published and the number of citations are the two main indicators reflecting the change of the number of papers and the development trend of the discipline.

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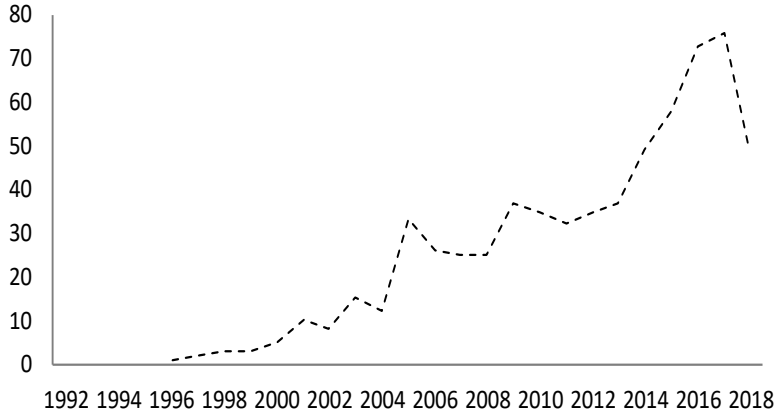

Figure 1. Quantity of papers on eco-efficiency studies

(1) From the point of view of the changes in the number of literatures, the research literature on ecological efficiency showed an overall fluctuating growth trend from 1992 to 2018 (Figure 1). It can be divided into three stages: initial exploration (1992-2004), fluctuated rise (2005-2013) and rapid development (after 2014). At the initial stage of exploration, little research has been done on ecological efficiency. In the rising stage of fluctuation, the number of research papers on ecological efficiency is gradually increasing. In the stage of rapid development, the number of literatures increased rapidly, from 37 in 2013 to 76 in 2017.

(2) According to the number of citations, there is a great difference in the number of citations among papers. The average number of references is 20.70; the median is 9; the standard deviation is 34.30. The number of papers with zero references accounted for 12.32%.

2.2 Core journals

By analyzing journals involved the study of ecological efficiency, we can analyze the research situation in this field in a broader scope. The journals in which papers are published more concentrated are shown in Table 1. The top ten journals account for 46.38% of the total publications. Among them, the Journal of Cleaner Production has the largest number of papers, totaling 136, accounting for 20.96% of the total number of papers published, nearly 100 more than the 39 papers of the second-ranked Journal of Industrial Ecology.

Table 1. Ten journals with the largest number of eco-efficiency papers published

Journal	factor of influence	literature quantity	Proportion (%)
Journal of Cleaner Production	5.651	136	20.96
Journal of Industrial Ecology	4.356	39	6.01
Ecological Economics	3.895	24	3.70
Sustainability	2.075	22	3.39
International Journal of Life Cycle Assessment	4.195	20	3.08
Journal of Environmental Management	4.005	18	2.77
Ecological Indicators	3.983	14	2.16
Resources Conservation and Recycling	5.120	10	1.54
Science of the Total Environment	4.610	9	1.39
International Journal of Sustainable Development and World Ecology	2.373	9	1.39

2.3 Major research institutions

Research institutions which published more than 5 papers and have more than 200 citations are listed in Table 2. The Chinese Academy of Sciences (CAS) is the research institution with the largest number of papers and citations; the figures are 18 and 489 respectively. Institutions of higher learning are the main organizations of literature publishing. For research institutions which have published more than five papers, 75% are higher learning institutions; for research institutions with more than 200 citations, 75% are higher learning institutions. It is noteworthy that the BASF AG

Group in Germany is the only company which is cited for more than 200 times, and the number of paper published reaches 5.

Table 2. Major Research Institutions Study on Ecological Efficiency

Research Institution	quantity of paper	Research Institution	citation frequency
Chinese Acad Sci, China	18	Chinese Acad Sci, China	489
Leiden Univ, the Netherlands	9	Leiden Univ, the Netherlands	464
Univ Valencia, Spain	8	Michigan State Univ, USA	377
Tsinghua Univ, China	8	Erasmus Univ, the Netherlands	343
Beijing Normal Univ, China	8	BASF AG, German	332
Univ Malaya, Malaysia	7	Univ Zaragoza, Spain	306
Finnish Environm Inst, Finland	7	Univ Valencia, Spain	266
Delft Univ Technol, the Netherlands	6	Helsinki Sch Econ, Finland	255
Dalhousie Univ, Canada	6	Finnish Environm Inst, Finland	244
Helsinki Univ Technol, Finland	6	Delft Univ Technol, Finland	243
		Univ Lueneburg, Germany	236
		Dalhousie Univ, Spain	221

3. Analysis on the Content Characteristics of Literature on Ecological Efficiency

3.1 Analysis of high frequency keywords

Through the statics of high frequency keywords in literature on ecological efficiency, we can find hot topics and research trends in this field in recent years. The keywords with frequent occurrences are arranged in order. The keywords occurred for more than five are analyzed as high frequency keywords and shown in Table 3. It can be found that the high frequency keywords cover a wide range, including research methods, research objects, theoretical framework, research background, influencing factors and so on.

Table 3. Statistics of high frequency keywords (unit: time).

Keywords	frequency	Keywords	frequency	Keywords	frequency
eco-efficiency	483	efficiency	10	environmental regulation	5
life cycle assessment	129	energy efficiency	10	global warming	5
data envelopment analysis	91	climate change	9	eco-industrial park	5
industrial ecology	38	energy	8	environment	5
sustainable development	36	eco-efficiency indicator	8	linear programming	5
sustainability	30	environmental indicator	7	environmental efficiency	5
environmental impact	22	economic performance	7	rebound effect	5
china	22	Benchmarking	7	pollution prevention	5
cleaner production	18	innovation	6	supply chain management	5
undesirable output	16	carbon footprint	6	co2 emissions	5
environmental performance	16	factor x	6	industrial symbiosis	5
Indicator	13	Decoupling	6	eco-effectiveness	5
environmental management	12	ecological footprint	6	eco-design	5
directional distance function	11	environmental pressures	5	municipal solid waste	5
recycling	11	Weighting	5	waste	5
resource efficiency	10	agriculture	5	transport	5
circular economy	10	regional eco-efficiency	5		

3.2 Analysis by combining multidimensional scaling method with clustering method

Multidimensional scale analysis can transfer data from the multi-dimensional space to

low-dimensional space for further positioning, analysis and classification. The cluster analysis can aggregate keywords into different categories according to similarities and differences. Therefore, this paper combines multi-dimensional scale analysis with the cluster analysis, and the results are shown in Figure 2. High frequency keywords are classified as eight hot topics, namely, “eco-efficiency measurement method“, “industrial ecology“, “carbon emission“, “life cycle assessment“, “environmental management“, “energy efficiency“, “circular economy“ and “ecology -economy relationship“.

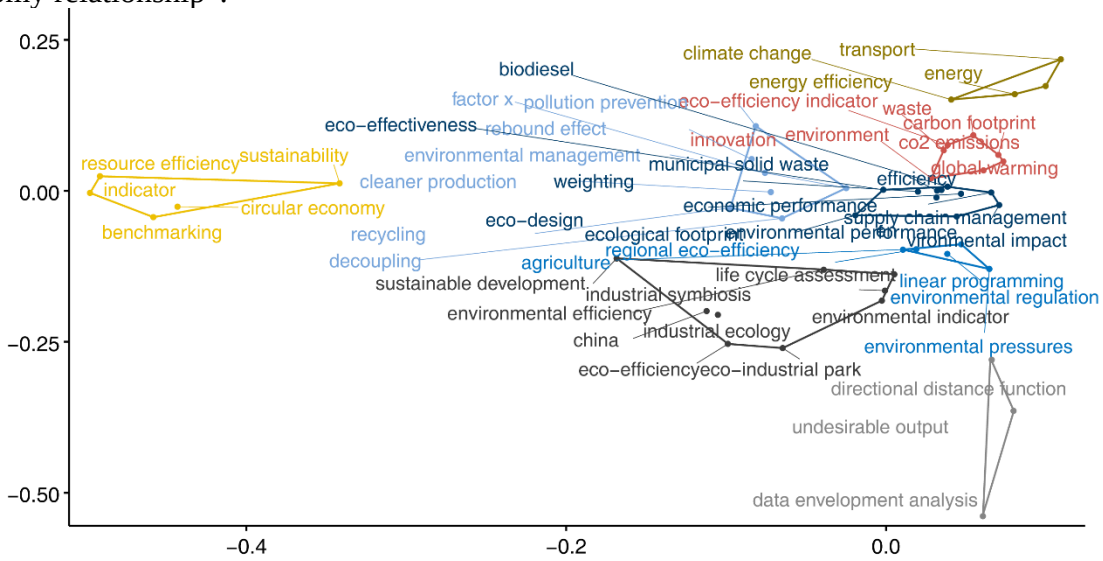

Figure 2. Visualization of keyword categorization results

4. Discussion of Hot Topics in the Field of Ecological Efficiency

Based on conclusions of previous studies, and combined with the summary of highly cited literature and interviews with experts, the following hot topics in eco-efficiency research are confirmed.

4.1 Methods on ecological efficiency evaluation

The ecological efficiency evaluation methods are mainly divided into two categories: the economic-environmental ratio method and the multi-input and multi-output evaluation method. The economic-environmental ratio method uses the ratio of economic value to environmental impact to measure ecological efficiency; the multi-input and multi-output evaluation method mainly uses data envelopment analysis to process multiple input and output indicators and measure ecological efficiency. Data envelopment analysis (DEA) has the problem of unexpected output in estimating ecological efficiency. Directional distance function is the main method of unexpected output in data envelopment analysis. There are 107 papers containing data envelopment analysis, unexpected output and directional distance function in headings or keywords, accounting for 16.49% of the total papers.

4.2 Combining with life cycle assessment

Life cycle assessment (LCA) is a research hotspot of ecological efficiency and a main tool to measure the ecological efficiency of micro-agents such as products and organizations. There are 119 articles about life cycle assessment, accounting for 18.34% of the total literature, and the 10 most cited articles. Among them, the papers of Kim, Bribian, Saling and Basset-Mens ranked 1, 2, 5 and 12 in the 649 references. These papers aim to measure the ecological efficiency of products and enterprises based on life cycle assessment.

4.3 Combination with industrial ecology

Industrial ecology is a new interdisciplinary subject which studies the interaction and relationship between industrial system and natural environment. At present, there are 39 articles

containing “industrial ecology“ in the keywords. The term of industrial ecology has rich connotations; material flow analysis and eco-industry are two important research directions of industrial ecology. If the keywords of “material flow analysis“, “energy analysis“, “energy flow“ and “eco-industry“ are added, there will be 57 literatures containing above keywords, indicating that the combination of industrial ecology is a hot issue in ecological research.

4.4 Measuring and calculating of agricultural ecological efficiency

Sustainable development of agriculture is a key issue concerning human survival and development. Agricultural ecological efficiency is an important indicator of agricultural sustainability and an important issue in ecological efficiency research. At present, there are 56 literatures about agricultural ecological efficiency. They can be divided into three categories. First is the measurement of the agricultural ecological efficiency of a certain area. Second is to measure the ecological efficiency of agricultural operators such as cooperatives and farms. For example, in 2009, Basset-Mens and colleagues estimated the ecological efficiency of New Zealand dairy farms. The paper was cited for 143 times. The third is to measure the ecological efficiency of agricultural products. For example, in 2008, Pelletier and colleagues compared and analyzed the ecological efficiency differences between traditional and organic farming of rapeseed, maize, soybean and wheat.

5. Summary

5.1 Conclusion

This paper takes 649 papers on eco-efficiency from the Web of Science as the research object, and uses the bibliometrics method to analyze the external characteristics, the features in contents and hot topics of eco-efficiency literatures. The main conclusions are as follows.

Firstly, the study of ecological efficiency is in the stage of rapid growth. From the quantity of literature, the research on ecological efficiency has gone through three stages: initial exploration (1992-2004), fluctuated rise (2005-2013) and rapid development (after 2014). Now the research is in the rapid development stage.

Secondly, the research perspectives of ecological efficiency are diversified. The mean and standard deviation of the network density of Keywords are very low, and the whole network is relatively scattered. However, the evaluation methods of ecological efficiency, the combination of ecological efficiency and life cycle assessment, the combination of ecological efficiency and industrial ecology, and the measurement of agricultural ecological efficiency are four hot topics in the study of ecological efficiency.

5.2 Prospects

First is the theoretical framework of ecological efficiency research. At present, there are various perspectives in the study of ecological efficiency, involving economics, management, ecology, agriculture, architecture and so on. There is no unified theoretical framework which can guide relevant research. Empirical research is the main research method; most studies are carried out based on empirical data. These papers measure the ecological efficiencies of different individuals, industries and regions and analyze the influencing factors, without paying attention to the discussion of theoretical principles. Therefore, the internal mechanism of the ecological efficiency of the research object is still the “black box“. There is an urgent need for a unified theoretical framework and more basic theoretical researches, so as to open the “black box“ and provide theoretical basis for the improvement of ecological efficiency of the research object.

Second is the practical application of ecological efficiency research. Eco-efficiency is an important index which can measure the development of green economy. Eco-efficiency has broad application prospects in relevant policy formulation and evaluation. However, in practice, the economic-environmental ratio evaluation method is the main method of regional development assessment, which is not convenient for the comprehensive investigation of various inputs and

negative outputs. According to the trend of research hotspots, the multi-input and multi-output evaluation method has broader application prospects in the field of ecological efficiency.

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