Research Trends and Perplexity of Green Manufacturing Under the Goal of "Carbon Peaking and Carbon Neutrality"--Based on Citespace & Coupling Model

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Abstract. In this paper, the reference theses are from CNKI and core database of WOS. A total of 503 theses published from 2016 to 2023 about this topic in China and abroad are collected. Citespace is mainly used to compare and analyze the number of published theses, authors, institutions and hotspots in this field at home and abroad. Then coupling model is used to study the coordination degree between the hottest topic of the moment and the development of domestic green manufacturing. The results show that: (1) In the past 7 years, the attention on the development of green manufacturing has been rising rapidly; (2) The cooperation between domestic scholars and institutions is not optimistic; (3) China takes the lead in the number of international publications, which reflects the high importance China attaches to the development of green manufacturing. (4) Nowadays, countries all over the world generally pay attention to the application of R&D investment and technological upgrades in the field of green manufacturing; (5) At present, there is a risk of imbalance between R&D investment and green manufacturing development in China.

1. Introduction

In the report of the Party's Twenty National Congress, Chinese President Xi Jinping pointed out that although we have made historic breakthroughs in ecological civilization construction, we still need the cooperation of various parties to fundamentally solve the problem of environmental pollution, including government support, rule of law, industrial autonomy, enterprise consciousness and public opinion supervision. In recent years, the "New Environmental Protection Act", "Made in China 2050", "New Pollution Control Action Plan" and other ecological governance laws have been introduced one after another. On the one hand, they show China's confidence and determination to realize the long-term goal of "carbon peaking and carbon neutrality". On the other hand, they show that China still has a lot of room for improvement in the prevention and control of heavy pollution.

Although the development of green manufacturing industry has made great progress compared with the early stage, many scholars still express their concern. For example, Jibhakate et al. (2021) [1] believe that variables in industrial units, such as emission management, have not been thoroughly investigated and have opportunities for improvement, so as to reduce manufacturing pollution by promoting green technology. However, Wan Panbing et al. (2021) [2] use sample grouping and differential model to empirically conclude that the current transformation of manufacturing industry requires difficult technological innovation, which is far beyond the enterprises' own capabilities. Zhang Jun (2021) [3] summarizes the deficiencies of China's green tax system in the way of review, including the unreasonable definition of penalties and the insignificant incentive effect. In addition, Qu Zhentao (2019) [4] and Li Xiaoyi (2022) [5] both use regression models to highlight that the government tax incentive effect is specific and needs to be treated according to local conditions and different industries. Lüthje (2021) [6], Wang Zitong (2022) [7], Xiao Jing et al. (2023) [8] and Xing Hui (2022) [9] respectively combines with the concept of digital economy and open innovation, which is currently popular, and proposes that there is still a lack of qualified talents, so that digital output cannot be effectively increased to promote enterprise internal R&D and external exploration to develop in phase. However, most of the theses ignore the analysis of research trends. In this paper, we not only make the tends visualized, but also use the coupling model to study the relationship between development of green manufacturing and the hottest concern currently in manufacturing industry.

2. Analysis of Research Trends Based on Citespace

2.1. Tool Introduction and Data Source

Citespace can visualize the content of literature and directly reflect the data distribution and the relationship between various data. Referring to the practices of Wang

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Qiaoling et al. [10] and Zhou Ting et al. [11], this paper discusses the research trend of the development of green manufacturing industry from 4 dimensions: time sequence, author, institutions and evolution of hotspots.

The data in this paper are based on CNKI and the core database of WOS. Considering the direction was not clear until the document of "Made in China 2025" issued in May 2015, we selected the papers which were done after 2016. Finally, 503 papers were obtained, including 217 papers in Chinese and 286 papers in English. After testing, 191 papers in Chinese and all papers in English are valid.

2.2. Temporal Statistical Comparison

This paper sorted the number of Chinese and foreign literature on green development of manufacturing by years from 2016 to now (Fig.1&2). From 2016 to 2020, the domestic attention on the development of green manufacturing industry shows a positive growing trend, however the increasing speed is slow until 2021. This phenomenon is closely related to the proposal of China's "carbon peaking and carbon neutrality" goal in 2020. In general, the trend of attention in China is basically consistent with that in the world.

Fig.1 Time Sequence of Publication Volume of Chinese literature.

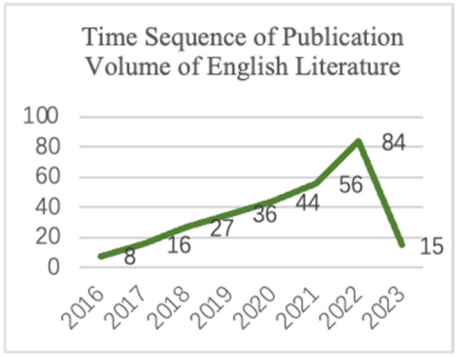

Fig.2 Time Sequence of Publication Volume of English literature.

2.3. Cooperations of Authors and Comparison

As the Fig.3 below, both at home and abroad, the number of scattered points on the network screen of author cooperation is quite considerable. It shows that although this field is hot and the number of scholars who have published papers is large, individual research still accounts for the majority, and the scientific research cooperation between domestic and foreign scholars needs to be strengthened.

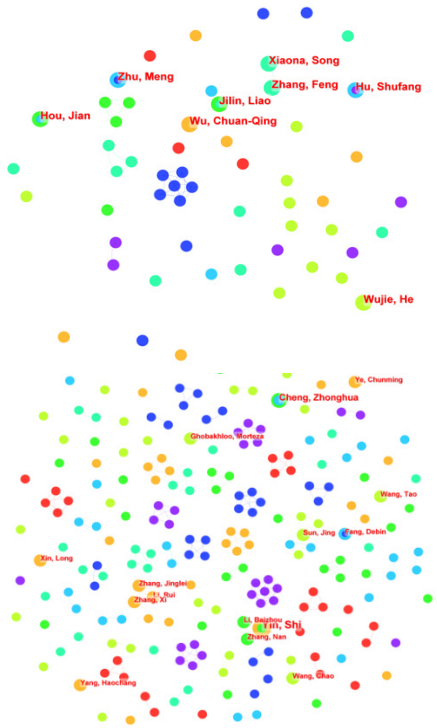

Fig.3 Cooperations of Authors and Comparison Between China & World.

2.4. Co-Occurrence of Institutions and Comparison

As the Fig.4 below, the institutions which have published the most theses are the schools of economics and management in China, with a number of more than 40. When it comes to the World, the Chinese Academy of Sciences is absolutely leading in this field with 9 published theses. The National University of Singapore followed with 6. In addition, China's well-known universities such as Tsinghua University et al. have also made great achievements in this field, with more than 100 publications. However, domestic institutions still need to strengthen the cooperations, which is inferior to the international institutions.

Fig.4 Co-Occurrence of Institutions and Comparison Between China & World.

2.5. Evolution of Hotspots in Chinese and International Literature

Analysis of Quality of Data. It can be seen from the Fig. 5&6 that the clustering module values(Q) of the Chinese and English theses are 0.7848 and 0.5852 respectively, which are both greater than 0.3, indicating that significant clustering and obvious categories of theses. Their average clustering contour values(S) are 0.9445 and 0.8252, which are both greater than 0.7, indicating that high clustering efficiency and high reliability. To sum up, the Chinese and foreign data selected in this paper are of high value and quality to research.

Analysis of Hotspots. In recent years, domestic researches on the green upgrading of manufacturing industry mainly involve policies and regulations, regional support, scientific research investment, personnel training and internal leadership. As can be seen from the Fig.5, the word with the highest frequency of keywords is "green transformation", followed by "manufacturing industry", "Yangtze River Economic Belt" and "environmental regulations", and finished with "green bonds", "investment efficiency", "Internet Plus" and "manufacturing transformation and upgrading". In combination with Fig.6, it shows that the early research focused on the green transformation of manufacturing industry in southeast coastal areas of China, and paid more attention to regulations, bonds and enterprise technological innovation, but ignored the output quality. Around 2019, the academic circle began to emphasize the importance of green investment efficiency. The discuss also changed from focusing on the self-efforts of high-pollution manufacturing industry in the early stage to be more and more refined and sunken. The focus not only expanded to the whole society, but also dove into small and micro enterprises. In response to the demands of the new era, new concepts such as "Internet Plus", "digital economy carbon reduction" and "digital empowerment development differences" have been put forward to amplify the significance of the combination of manufacturing and modern science and technology for the green transformation and upgrading of the manufacturing industry.

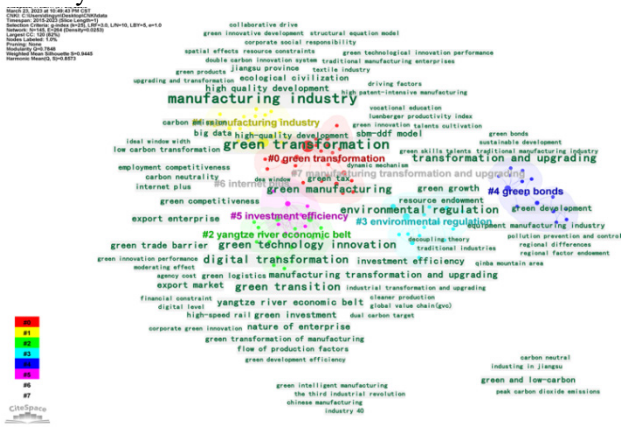

Fig.5 Key Words of Domestic Green Manufacturing Development Cluster Graph.

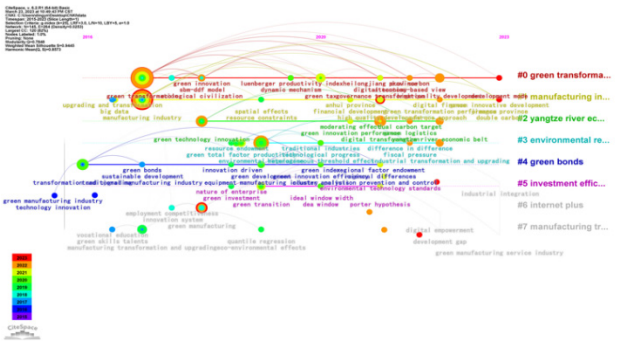

Fig.6 Time Distribution Map of Domestic Green Manufacturing Development Cluster Graph.

The process of development of manufacturing industry in the world is basically the same as that in China. As can be seen from the Fig.7, the word with the highest frequency of keywords is "environmental regulations", followed by "green chemistry", "green total factor productivity" and "carbon emission", and finished with "biomass", "iron oxide reduction", "green technology innovation", "green innovation" and "energy efficiency". It shows that more attention is paid to the formulation of laws and regulations and the innovation of materials required for manufacturing. In combination with the time distribution map of the Fig.8, it shows that in the early stage of the research, biomass, iron oxide reduction, carbon emission, green chemistry and environmental regulations were paid more attention. At this time, the research focused on the combination of raw material improvement and external regulations, involving hot topics like supply chain management, sustainability, carbon dioxide conversion, etc. Around 2018, scholars began to pay attention to green total factor productivity, green technological innovation, green innovation and energy efficiency, with hot topics including digital economy, carbon credit, decomposition analysis, etc.

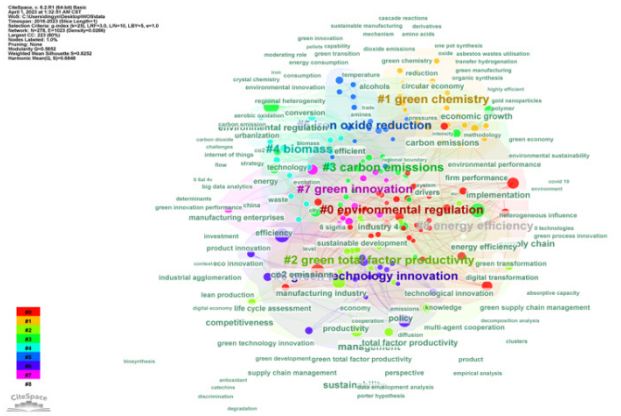

Fig.7 Key Words of Foreign Green Manufacturing Development Cluster Graph.

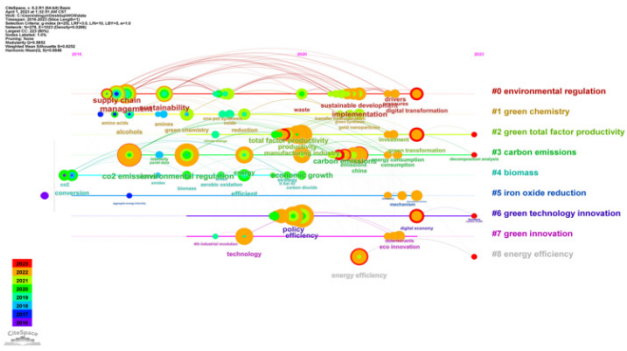

Fig.8 Time Distribution Map of Foreign Green Manufacturing Development Cluster Graph.

3. Analysis of Confusion Based on Coupling Model

The visualization analysis above shows that nowadays, whether domestic or international, research hotspot is the R&D investment to develop the digitization. The digitization enables the green development of the manufacturing industry [12] and change the fragmentation situation that only focuses on a specific process or object. This also helps inspire scholars to make more multi-perspective and whole-process quantitative researches, strengthening the scientific and reliability of the conclusions. However, most of the theses ignore the research on input efficiency. Inefficient investment means another form of waste of resources. In this paper, the coupling model is used to study the relationship between development of green manufacturing and R&D investment in manufacturing industry.

Data are sourced from China Environmental Statistics Yearbook, China Environmental Statistics Annual Report, Comprehensive Environmental Protection List (2021 Edition) and GuoTaiAn Database. Considering the representativeness, timeliness and completeness of the indicators, this paper sorted out the data of development of green manufacturing and R&D investment of the manufacturing industry during 2016-2020. Development of green manufacturing is measured from three aspects: water pollution, air pollution and solid & hazardous waste of manufacturing industry, including 29 sub-sectors such as agricultural and sideline food processing industry, food manufacturing industry, and so on. R&D investment includes three indexes: R&D expenditure, R&D personnel and the number of effective green inventions.

Tab.1 Development of Green Manufacturing from 2016 to 2020.

Development of green manufacturing	2016	2017	2018	2019	2020
Water pollution (unit: ton)	1,180,012	875,212	786,829	744,160	411,275
Air pollution (unit: ton)	21,078,110	15,874,886	14,537,572	13,858,201	6,838,946
Solid &Hazardous waste (Unit: 10,000 tons)	146,596.43	146,760.01	155,497.65	165,056.88	140,350.97

Tab.2 R&D Investment in Manufacturing from 2016 to 2020.

R&D investment in manufacturing	2016	2017	2018	2019	2020
R&D expenditure (Unit: 100 million yuan)	10,449.63	11,447.11	12,446.25	13,493.20	14,726.75
R&D personnel (unit: pp)	2,578,171	2,612,622	2,884,418	3,044,918	3,344,378
Number of effective green inventions (unit: pcs)	744,475	903,683	1,059,323	1,171,884	1,394,186

3.1. Entropy method to determine the weight

The data processing method of this paper refers to the theses of Meng Qingjun [13] and other scholars, and adopts the objective weighting method to construct a matrix for m evaluation objects and n indexes, the formula is $X = (x_{ij})_{m\times n}$, The greater the information entropy value (e_j) is, the greater the degree of dispersion and the weight represented by the data. The steps of determining weight by entropy method as follows:

1. Non-Dimensional Processing of Indicators:

Positive indicators:

$$X_{ij} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \quad (1)$$

Adverse indicators:

$$X_{ij} = \frac{min(x_{ij}) - x_{ij}}{max(x_{ij}) - min(x_{ij})} \quad (2)$$

The above formula X_{ij} is the result of standardized processing, and x_{ij} is the original data.

2. Calculate the proportion of j index:

$$W_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \quad (3)$$

3. Calculate the entropy e_j:

$$e_j = -\frac{1}{ln\, m}\left(\sum_{i=1}^{m} W_{ij}\, ln\, W_{ij}\right) \quad (4)$$

$$(0 \le e_j \le 1)$$

4. The entropy redundancy d_j of j index:

$$d_j = 1 - e_j \quad (5)$$

5. Calculate the weight of j index s_j:

$$s_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (6)$$

6. Comprehensive evaluation of the calculation system V:

$$V = \sum_{j=1}^{n} s_j X_{ij} \quad (7)$$

The index system of development of green manufacturing and R&D investment in manufacturing from 2016 to 2020 is shown in the Tab.3 and Tab.4 respectively.

Tab.3 Index System of Development of Green Manufacturing.

System layer	Index layer	Attribute	Weight s_j
Development of green manufacturing	Water pollution/ton	-	0.3313
	Air pollution/ton	-	0.3512
	Solid & Hazardous waste/mt	-	0.3175

Tab.4 Index System of R&D Investment in Manufacturing.

System layer	Index layer	Attribute	Weight s_j
R&D investment in manufacturing	R&D expenditure /100 million yuan	+	0.3333
	R&D personnel /pp	+	0.3333
	Number of effective green inventions /pcs	+	0.3333

3.2. Construct a coupled coordination model

In order to explore the coordinated development relationship between development of green manufacturing and R&D investment in manufacturing, we use coupling degree and coupling coordination degree to further process the data. The coupling degree can measure the degree of interaction between two systems. The higher the degree is, the closer the relationship between the systems and the greater the mutual influence is. The coupling coordination degree is used to evaluate whether the development of the systems is coordinated. The larger the coupling coordination degree is, the better the coordination state between the systems is.

1. Calculate the comprehensive coordination index T:

$$T = \alpha V_1 + \beta V_2 \quad (8)$$

In the above equation, α and β respectively represent the weight of the development of green manufacturing and R&D investment in manufacturing. From the perspective of reference and actual practice, the two indicators penetrate and cross each other, so it is considered that the two indicators are equally important, taking α= β=0.5; V_1 and V_2 respectively represent the comprehensive evaluation value of e the development of green manufacturing and R&D investment in manufacturing. The same below.

2. Calculate the coupling degree C:

$$C = \left[\frac{v_1 \times v_2}{\left(\frac{v_1 + v_2}{2}\right)^2} \right]^{1/2} \quad (9)$$

3. Calculate coupling coordination degree D:

$$D = \sqrt{C \times T} \quad (10)$$

$D \in [0, 1]$. The larger the D is, the higher the degree of coordinated development between systems is; otherwise, the imbalance is.

According to the classification of coupling degree in existing theses and the data above, the Tab.5 is obtained. Data show that the development of green manufacturing and R&D investment in manufacturing in 2016 were mildly unbalanced, indicating that the efficiency of domestic R&D investment at this time was still relatively low, and the input of manpower, material and financial resources couldn't be well converted into ecological value. The degree of coupling coordination has been on the rise during 2016-2019, and reached intermediate coordination in 2019, indicating that China has been striving for high-quality production mode at this stage, which is worthy of acknowledgement. However, the coupling coordination degree dropped to a mild imbalance in 2020. The reasons may be as follows: (1) the previous R&D investment has been unable to meet the emerging pollution control requirements, and the quantity of pollution has undergone qualitative change, requiring more input to control; (2) The form of pollution has undergone qualitative change, and the updating speed of related technologies can't match the upgrade of manufacturing industry or effectively deal with the new forms of pollution, so it is necessary to innovate technologies and improve the quality of R&D personnel.

Tab.5 Calculation Results of Coupling Coordination Degree Between the Development of Green Manufacturing and R&D Investment in Manufacturing.

Time	C	T	D	Coordination level	Degree of coupling coordination
2016	0.199	0.500	0.315	4	Mild disorder
2017	0.779	0.387	0.549	6	Forced coordination
2018	0.995	0.489	0.698	7	Primary coordination
2019	0.992	0.560	0.746	8	Intermediate coordination
2020	0.199	0.500	0.315	4	Mild disorder

4. Conclusion

Through the review and visualization analysis of Chinese and international theses from 2016 to 2023, the following conclusions are drawn: (1) From the number of relevant theses, the domestic and international attention to the development of green manufacturing industry continues to rise, especially after the 2020, indicating that the development of green manufacturing industry has become a hot research field at home and abroad; (2) From the results of co-occurrence of authors' cooperation network and institutions, it can be seen that Chinese scholars and institutions have been actively exploring the field of green manufacturing in the world, who have international academic influence on related topics. However, both at home and abroad, independent individuals and institutions still account for the majority in this field, and cooperation

between domestic and foreign scholars and institutions needs to be strengthened. In addition, well-known universities and institutions in China seem to prefer international journals, publishing more articles in international journals than in domestic journals. Dose it mean the quality of native journals in this field needs to be improved? (3) China takes the lead in the number of published theses, which shows that China attaches great importance to the field. In addition, the countries involved are spread across five continents, indicating that with the strengthening of environmental protection awareness of people around the world and the improvement of living environment requirements, countries around the world are generally concerned about the green transformation of manufacturing industry, and the transformation and upgrading of high-pollution manufacturing industry is imminent. (4) From the perspective of keyword clustering and time distribution map, in the 21st century, with the policy orientation and scientific and technological progress, the application of R&D investment and technological development in the field of green manufacturing industry has been paid attention to worldwide, and the researches from the single perspective in the early stage has changed to the quantitative research from the multi-perspective and the whole process. (5) From the coupling analysis results of development of domestic green manufacturing industry and R&D investment, there is a risk of imbalance and the investment efficiency needs to be strengthened. How to ensure manufacturing enterprises to achieve efficient R&D investment will likely become the focus of the next discussion, such as increasing input or technological upgrading, development of digital economy and so on. There is no doubt that it's not enough for enterprises to change by themselves. It requires the joint efforts of government, society and enterprises. Of course, academic circle also plays an important role of guiding the direction in this process.

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