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Bibliometric and Content Analysis: The Role of Sustainable Manufacturing in Fertilizer Distribution

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ABSTRACT

The fertilizer industry has a strategic role in supporting food security, however challenges in inefficient distribution can hamper the sustainability of the agricultural sector. This research aims to analyze publication trends related to sustainable manufacturing in fertilizer distribution and its impact on Environmental, Social and Governance (ESG) aspects. Data was obtained from the Scopus and Web of Science databases with a total of 723 articles from Scopus and 763 articles from Web of Science. After filtering based on document type (articles and reviews), language (English), access (open access), and year of publication (2015-2024), 167 articles remained for analysis. The research methods used are bibliometric analysis to identify publication patterns, co-word analysis, and content analysis to explore main findings in the literature. The research results show that the application of sustainable manufacturing in fertilizer distribution has a positive impact on environmental, social and governance aspects. The use of technology such as Distribution Planning and Control System (DPCS) and Truck Tracking (INDIGO Tracker) increases distribution efficiency by reducing carbon emissions and fuel consumption. Web-based distribution information systems improve transparency and accountability, minimize waste and ensure timely distribution. On the social side, programs such as the Farmers Card help equalize access to fertilizer for farmers, reducing social inequality. In the governance aspect, this technology strengthens supervision and increases trust between farmers and stakeholders. The results of this research also confirm that a sustainability-based approach in fertilizer manufacturing and distribution can be an effective strategy to support more efficient and environmentally friendly agriculture.

Keywords: *Bibliometric Analysis, Fertilizer Distribution, Manufacturing Sustainability*

ABSTRAK

Industri pupuk memiliki peran strategis dalam mendukung ketahanan pangan, namun tantangan distribusi yang tidak efisien dapat menghambat keberlanjutan sektor pertanian. Penelitian ini bertujuan untuk menganalisis tren publikasi terkait manufaktur berkelanjutan dalam distribusi pupuk dan dampaknya terhadap aspek Environmental, Social and Governance (ESG). Data diperoleh dari *database* Scopus dan Web of Science dengan total 723 artikel dari Scopus dan 763 artikel dari Web of Science. Setelah disaring berdasarkan jenis dokumen (artikel dan ulasan), bahasa (bahasa Inggris), akses (akses terbuka), dan tahun publikasi (2015-2024), 167 artikel tersisa untuk dianalisis. Metode penelitian yang digunakan adalah analisis bibliometrik untuk mengidentifikasi pola publikasi, analisis co-word, dan analisis isi untuk mengeksplorasi temuan utama dalam literatur. Hasil penelitian menunjukkan bahwa penerapan manufaktur berkelanjutan dalam distribusi pupuk berdampak positif pada aspek lingkungan, sosial dan tata kelola. Penggunaan teknologi seperti Distribution Planning and Control System (DPCS) dan Truck Tracking (INDIGO Tracker) meningkatkan efisiensi distribusi dengan mengurangi emisi karbon dan konsumsi

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bahan bakar. Sistem informasi distribusi berbasis web meningkatkan transparansi dan akuntabilitas, meminimalkan pemborosan, dan memastikan distribusi tepat waktu. Di sisi sosial, program seperti Kartu Petani membantu pemerataan akses pupuk bagi petani, mengurangi ketimpangan sosial. Pada aspek tata kelola, teknologi ini memperkuat pengawasan dan meningkatkan kepercayaan antara petani dan pemangku kepentingan. Hasil penelitian ini juga menegaskan bahwa pendekatan berbasis keberlanjutan dalam pembuatan dan distribusi pupuk dapat menjadi strategi yang efektif untuk mendukung pertanian yang lebih efisien dan ramah lingkungan.

Kata Kunci: Analisis Bibliometrik, Distribusi Pupuk, Keberlanjutan Manufaktur

INTRODUCTION

The fertilizer industry plays a crucial role in supporting the agricultural sector, which is one of the main drivers of the economy (Fahmid *et al*., 2022). As an agrarian country, many regions rely heavily on the availability of fertilizers to enhance agricultural productivity and meet national food demands. The stability of fertilizer supply is a key element in ensuring food security and the well-being of farmers (Fahmid *et al*., 2022). However, fertilizer distribution faces various challenges that hinder its efficiency and effectiveness. Delays in delivery, stock shortages in certain areas, and high logistics costs are the main problems in the fertilizer supply chain (Shabur *et al*., 2024). These issues are further exacerbated by inaccurate data in fertilizer distribution, leading to misallocation and potential declines in farmer productivity. Several efforts have been made to improve transparency and accuracy in the distribution process, including the implementation of more advanced digital systems.

In addition to distribution challenges, inefficient fertilizer use also poses negative environmental impacts. Excessive or improper fertilizer application can lead to soil degradation, water pollution, and increased greenhouse gas emissions (Pusat Perencanaan Strategis dan Manajemen Risiko Pangan Indonesia, 2021). As a mitigation measure, various sustainability strategies have been implemented, including the development of eco-friendly products and the adoption of circular economy concepts in fertilizer industry operations. These efforts focus on reducing carbon emissions and improving resource efficiency.

With the growing global awareness of sustainability, the concept of sustainable manufacturing has become a key focus in the fertilizer industry. Sustainable manufacturing in fertilizer distribution encompasses the use of clean energy, technology-driven logistics optimization, and policies that enhance supply chain efficiency. Technological innovations, such as green ammonia production and clean energy policies, also play a role in achieving a more sustainable industry (Bhatt *et al*., 2020).

Beyond environmental aspects, sustainability in the fertilizer industry also covers social and economic dimensions. Various initiatives have been developed to enhance farmers' well-being and support surrounding communities through partnership programs and corporate social responsibility efforts. These programs

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aim to help farmers manage their land more efficiently and sustainably while ensuring equitable access to high-quality fertilizers.

Despite the importance of sustainability in fertilizer distribution, limited research has specifically explored trends in sustainable manufacturing within this process—even though efficient distribution is an integral part of a sustainable production system. Bibliometric analysis can be utilized to identify patterns in scientific publications, assess research developments in this field, and evaluate existing scholarly contributions. This method helps uncover publication trends by analyzing the number, patterns, and emerging research topics over time (Donthu *et al*., 2021). Through techniques such as citation analysis, co-word analysis, and bibliometric mapping, researchers can identify trending topics, collaborations among authors or institutions, and the most influential journals in the field. Additionally, by examining frequently occurring keywords and publication growth patterns, this analysis provides insights into the future direction of research, enabling academics and stakeholders to align their research strategies with the latest scientific developments.

Using this approach, researchers can explore how sustainability implementation in fertilizer distribution impacts Environmental, Social, and Governance (ESG) aspects and identify research gaps for future studies. This research aims to provide a deeper understanding of the factors influencing the effectiveness of sustainable manufacturing in fertilizer distribution. Key factors to consider include technological readiness, government policies, and industry preparedness in adopting sustainability-driven innovations. Analyzing these factors is expected to offer valuable insights for stakeholders in designing more effective strategies to improve the efficiency and sustainability of the fertilizer industry.

Furthermore, this study seeks to offer recommendations for future research in developing innovative methods and technologies that support sustainability in the fertilizer sector. Possible directions for future studies include the advancement of digital distribution systems, the integration of blockchain technology in the fertilizer supply chain, and the optimization of AI-driven fertilizer management. By pursuing these innovations, this research aspires to contribute significantly to the transformation of the fertilizer industry into a more efficient, sustainable, and environmentally friendly system.

RESEARCH METHOD

This study employs two different analytical approaches: bibliometric analysis and content analysis. This strategic combination allows for the utilization of the strengths of each method, providing a comprehensive and multidimensional exploration of the topic discussed. Bibliometric analysis is a research method using a quantitative approach to evaluate and analyze bibliographic data, such as scientific articles, books, and other academic documents (Donthu *et al*., 2021b). This approach is based on verifiable quantitative data, primarily from indexed publications, ensuring the robustness of the method by avoiding the subjectivity of expert opinions (Alsharif & Baharun, 2020).

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To complement the results of the bibliometric analysis, content analysis is used as a qualitative method to investigate the content of texts, visuals, or audio in documents, media, or other sources. In this research, content analysis is used to identify patterns, themes, and in-depth insights (Ellegaard & Wallin, 2015). Content analysis complements the bibliometric analysis by providing a deeper qualitative dimension to the data that has been identified quantitatively. Unlike bibliometric analysis, which focuses on measuring publication patterns and relationships between documents, content analysis aims to explore the meaning, themes, and patterns contained in texts, images, or other media elements (Donthu *et al*., 2021b). By analyzing the content of relevant documents or articles, this method helps uncover deeper insights into the issues discussed, including motivations, perceptions, and thematic trends.

This research analyzes three main dimensions: 1) Bibliometric citation analysis; 2) Co-authorship collaboration analysis in bibliometrics; 3) Content analysis. The analysis process is conducted using the "Bibliometrix" package in RStudio, equipped with "Biblioshiny" (Aria & Cuccurullo, 2017). This package not only supports data analysis but also generates visualizations that can be further interpreted. The study includes all articles relevant to the themes of sustainable practices and fertilizer distribution processes. Data sources are obtained from two indexed databases, Scopus and Web of Science. To identify relevant literature, a keyword search criterion is used, covering "Sustainable manufacturing" and "Distribution Fertilizer."

During the keyword search process, various alternative synonyms are used to obtain more comprehensive results. Therefore, the keywords used include: *(("Sustainab" OR "Green" OR "triple bottom line" OR "TBL" OR "Eco-efficiency" OR "eco-sustainability" OR "sustainable manufacturing"*) AND *("slow-release fertilizer*" OR "controlled release fertilizer*" OR "sustained release fertilizer*" OR "stabilized fertilizer*")* (Bhatt *et al*., 2020b; Li & Li, 2024).

RESULTS AND DISCUSSION

Bibliometric Analysis Results

This section will explain the research steps conducted using the Systematic Literature Review (SLR) method based on the PRISMA Flowchart. The literature review process consists of four main stages: 1) identification, 2) screening, 3) eligibility, and 4) analysis. These four stages are systematically performed to ensure that the literature used is relevant and meets the research criteria, as shown in Figure 3.

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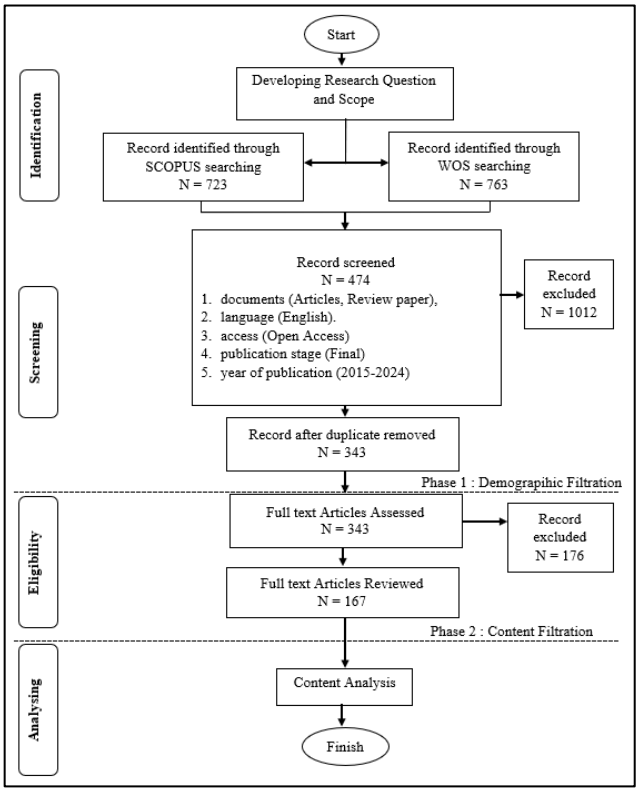

Figure 1. IPA Diagram

Identification Process

This study covers all articles related to sustainable manufacturing and fertilizer distribution. The first step in this research involves selecting databases to extract data for bibliometric analysis. In this study, two databases were used: Scopus and Web of Science. In the second step, relevant literature was searched using appropriate keywords. There were two criteria in our keyword search: sustainable manufacturing and fertilizer distribution. Based on these keywords, we retrieved 723 articles from Scopus and 763 articles from Web of Science. The details of the search string used can be found in Table 1.

Table 1. Keywords Sustainability Manufacturing and Fertilizers Distribution

Topic	String
Sustainability Manufacturing	(“Sustainab*” OR “Green” OR “triple bottom line” OR “TBL” OR “Ecoefficiency” OR “eco-sustainability” OR “*sustainable manufacturing*”)
Fertilizer Distribution	("*slow release fertilizer**" OR "*controlled release fertilizer**" OR "*sustained release fertilizer**" OR "*stabilized fertilizer**")
	Full String (“*Sustainab∗*” OR “*Green*” OR “*triple bottom line*” OR “TBL” OR “*Eco-efficiency*” OR “*eco-sustainability*” OR “*sustainable manufacturing*”) AND ("*slow release fertilizer**" OR "*controlled*

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	release fertilizer" OR "*sustained release fertilizer*" OR "*stabilized fertilizer*")

Screening Process

All results obtained from the data identification process, totaling 474 articles, will be filtered and included based on the established criteria. There are five criteria used in this study: document type (articles and review papers), language (English), access (Open Access), publication stage (final), and publication year (2015-2024). After the screening process, 197 articles were obtained from Scopus and 277 articles from Web of Science.

The search results were then downloaded, with the exported information including citation details, bibliographic information, abstracts & keywords, and other relevant data. From both data sources, the data was processed using R Studio software to remove duplicates, resulting in 343 articles.

Eligibility Process

This stage involves rechecking the literature that has been downloaded. This review is done through a manual data screening process by thoroughly understanding the abstracts. The process consists of two steps: in the first step, a review is conducted on the title, abstract, and keywords. Of the 343 articles analyzed, 285 articles meet the criteria.

In the second step, a comprehensive review of the article's content is conducted to verify whether the article aligns with the analysis requirements. If any literature is found to be irrelevant to the topic of sustainability manufacturing and fertilizer distribution, that data will be removed and not used. From the 343 articles analyzed in the first step, 167 articles meet the criteria to be selected as primary studies based on the SLR conducted.

Bibliometric Analysis

Main Information

The bibliometric analysis begins by describing the main information as explained in Figure 2

Figure 2. Main Information

The bibliometric analysis of the study titled "Bibliometric and Content Analysis: The Role of Sustainability Manufacturing in Fertilizer Distribution" provides a comprehensive overview of the academic landscape during the period from 2015 to

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2024. This study is based on 104 diverse sources, including journals, books, and other academic materials, totaling 167 documents. The annual growth rate of 9.6% indicates an increase in interest and productivity, albeit still relatively low in this research field over that period. The average document age is 2.72 years, which reflects the focus on the most recent and contemporary literature contributions. The average citation rate of 12.15 citations per document shows a substantial impact, reflecting the influence of this research within the academic community. With 4944 references, this analysis is grounded on a broad bibliographic foundation, illustrating the depth and breadth of the literature considered. Exploration of 641 Author's Keywords reflects the diverse and multidimensional aspects of the research.

This study involves 872 authors, demonstrating the collaborative nature of the research, with 4 documents written by individual authors and an average of 6.16 authors per document. The international collaboration percentage of 11.38% reflects global cooperation that contributes a diverse and comprehensive perspective. The document types analyzed are dominated by articles (101), with other variations such as "article" (1) and "article; early access" (1), highlighting the academic focus in the literature. Overall, this bibliometric analysis reveals a dynamic and strong landscape, indicating an increase in interest, collaborative efforts, and a rich diversity of sources that support the understanding of fertilizer distribution and sustainability manufacturing.

Publication Trend

The analysis of publication trends is conducted by reviewing the changes and developments of scholarly articles in a specific field or subject over a defined period. The results displayed in Figure 5 show the publication patterns related to sustainability manufacturing and its impact on fertilizer distribution from 2015 to 2024, based on a compilation of 167 documents collected.

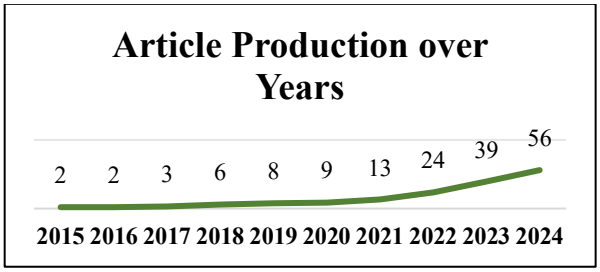

Figure 3. Article Production over Years

The publication trend analysis of the research titled "Bibliometric and Content Analysis: The Role of Sustainability Manufacturing in Fertilizer Distribution" reflects a clear evolution in scientific output during the specified period. In 2015, there were only 2 articles addressing this topic, indicating relatively low research interest in its early stages. The subsequent years showed significant growth in the number of publications, with 8 articles in 2019, marking increased attention towards the topic. This momentum continued to rise, reaching its peak in 2024 with 56 articles contributing to the development of research on sustainable manufacturing in

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fertilizer distribution. These fluctuations may reflect a need for more focused research or an indication of stabilization on this topic. The observed pattern highlights the dynamic nature of academic engagement with the impact of sustainability manufacturing on fertilizer distribution, offering valuable insights into emerging trends within this research domain.

Trend Topics and Co-word analysis of high-frequency keywords

Trend Topics and Co-word Analysis on high-frequency keywords reveal significant patterns and themes within the research landscape titled "Bibliometric and Content Analysis: The Role of Sustainability Manufacturing in Fertilizer Distribution," as presented in Tables 3 and 4. These analyses identify the most dominant topics and the most frequently appearing words in the literature.

Table 2. Trend Topic

Topic	Frequency
Nitrogen	30
Phosphorus	30
Fertilizer	27
Fertilizers	26
Soil	24
Recycling	17

Table 2 presents the frequency distribution of various research topics in the bibliometric analysis. The term "nitrogen" emerged as the most frequently explored topic, appearing in 30 studies. This was closely followed by the topic "phosphorus," which was the focus of 30 studies as well. "Fertilizer" and "fertilizers" were discussed in 27 and 26 studies, respectively, reflecting significant interest in these methodological approaches. Additionally, the topics "soil" and "recycling" were each studied in 24 and 17 studies. This analysis provides an overview of the current bibliometric research landscape, highlighting the dominance of certain themes in the academic literature. These findings can offer guidance for future research and provide insights into the ongoing academic discourse in the selected field. Researchers can leverage these trends to identify gaps, determine popular research areas, and shape the direction of future studies in bibliometrics.

Table 3. Most Frequent Words

Words	Occurrences
Nitrogen	30
Phosphorus	30
Fertilizer	27
Fertilizers	26
Soil	24
Recycling	17
Urea	17

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Slow-release fertilizers	16
Agriculture	12
Growth	9

Table 3 provides information regarding the most frequently occurring keywords, further emphasizing the key elements in the research. "Nitrogen" and "phosphorus" remain the most dominant terms with 30 occurrences, followed by "fertilizer" and "fertilizers" with 27 occurrences, "soil" with 24, "recycling" and "urea" with 17, and "slow-release fertilizers" with 16 occurrences. Other important terms include "agriculture," "growth," "alternative agriculture," "sustainable development," and "agri-manufacturing," each contributing to the rich vocabulary that characterizes this research domain. Additionally, the co-occurrence network mapping of these keywords will be displayed as shown in Figure 4.

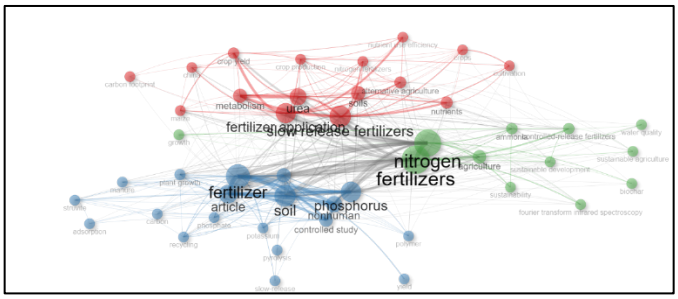

Figure 4. Co-occurence Network Mapping

The Co-occurrence Network Mapping displayed in the exported data visually represents the relationships between key terms. Specifically, "nitrogen" and "phosphorus" emerge as central nodes in the network, highlighting their significant roles in connecting various thematic clusters. This data also offers additional insights through metrics such as betweenness, closeness, and PageRank, emphasizing the importance of certain terms, including the unexpected prominence of "fertilizer" and its strong influence within the network. This co-word analysis provides valuable insights into the dominant themes and the interconnections among frequently occurring keywords in research on sustainable manufacturing in fertilizer distribution. It opens up opportunities for a deeper understanding of the current research landscape and the potential directions for future investigations.

Countries Production Analysis

The Countries Production Analysis provides an overview of the distribution of scientific output across various countries related to the research topic "Bibliometric and Content Analysis: The Role of Sustainability Manufacturing in Fertilizer Distribution." Table 4 presents a comprehensive review of the articles produced by each country.

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Table 4. Countries Production

Country	Articles
CHINA	101
BRAZIL	31
ITALY	23
USA	22
INDIA	17

Table 4 shows the distribution of scientific articles across different countries, providing insights into the contributions of research in this bibliometric analysis. China emerges as the primary contributor with 101 articles, underscoring its significant role in the academic landscape. Brazil ranks second with 31 articles, reflecting the growing impact of research output in the region. Italy, the United States, and India also exhibit substantial participation, producing 23, 22, and 17 articles, respectively, highlighting the geographical diversity in research efforts.

The distribution of articles across countries reflects the collaborative and multidimensional nature of the international research landscape. The varying levels of research output may be influenced by factors such as the size and resources of academic communities, research infrastructure, and regional research priorities. This country-based production analysis provides a comprehensive view of the geographical distribution of research efforts in bibliometric studies, enriching the understanding of global academic contributions to the chosen field.

Thematic Maps Analysis

Thematic Map Analysis provides a visual representation of the emergence and thematic clustering in the research on “Bibliometric and Content Analysis: The Role of Sustainable Manufacturing in Fertilizer Distribution”. The results of the thematic maps analysis are depicted as shown in Figure 5.

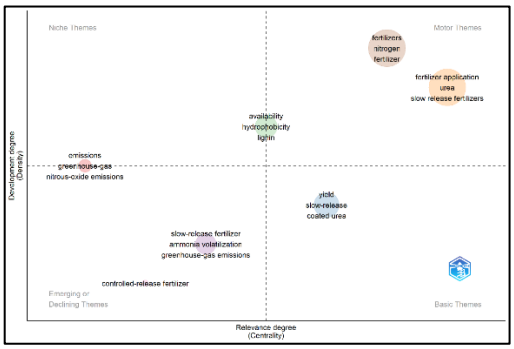

Figure 5. Thematic Map Analysis

Thematic maps analysis provides a deeper understanding of research themes, categorizing them into different quadrants to highlight their significance and interrelations. In the Motor Themes quadrant, topics such as 'fertilizers', 'nitrogen', 'fertilizer application', 'urea', and 'slow-release fertilizers' dominate, showing moderate emergence and significant betweenness centrality. These themes act as

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driving forces, connecting various concepts in the dataset, underscoring their influential role in academic discussions.

The Niche Themes quadrant is marked by higher emergence and substantial betweenness centrality, with focal points like 'emissions', 'greenhouse gas', 'nitrous-oxide emissions', 'availability', 'hydrophobicity', and 'lignin'. These themes occupy a central position in linking various aspects of research, reflecting their prominence and importance within the dataset. They represent concentrated areas of interest that likely indicate ongoing, influential discussions within the academic community.

In the Emerging or Declining Themes quadrant, topics such as 'controlled-release fertilizer', 'ammonia volatilization', 'greenhouse-gas emissions', and 'slow-release fertilizer' stand out. These themes display varying levels of emergence and betweenness centrality, indicating a dynamic shift or developing trends in the research landscape. The evolving nature of these themes suggests that they may either gain prominence or experience a shift in academic focus over time.

Additionally, in the Basic Themes quadrant, topics like 'yield', 'slow-release', and 'coated urea' are identified with lower emergence and betweenness centrality. Positioned as basic themes, these topics contribute to the overall thematic map but do not serve as major connectors in the dataset. They provide fundamental concepts that support the broader context of the research, but do not always act as primary hubs.

This thematic map analysis offers a comprehensive view of the research landscape, revealing the centrality and emergence of various thematic clusters. The classification into Motor, Niche, Emerging or Declining, and Basic Themes provides researchers with a valuable framework to navigate and understand the complex relationships between different research concepts

The Impact of Sustainable Manufacturing on Fertilizer Distribution

The bibliometric results previously presented indicate that the topic of sustainable manufacturing is gaining increasing attention within the context of fertilizer distribution. As shown in Figure 5, the number of articles discussing this topic has significantly increased year by year. This trend reflects the urgency and relevance of sustainable manufacturing in supporting the efficiency and sustainability of the fertilizer supply chain, which is a key factor in the agricultural sector.

Sustainable manufacturing refers to processes that minimize negative environmental impacts, enhance resource efficiency, and provide long-term economic and social benefits. In the context of fertilizer distribution, the application of sustainable manufacturing principles has the potential to improve logistics systems, reduce carbon emissions, and ensure more stable and sustainable fertilizer availability for farmers. The impact of sustainable manufacturing on fertilizer distribution can be analyzed through three main aspects within the Environmental, Social, and Governance (ESG) framework. The following are some of the practices or implementations of sustainable manufacturing that have been applied to fertilizer distribution processes in Indonesia, as shown in Table 5.

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Table 5. Implementation of Sustainable Manufacturing

No	Efforts in Implementation	Environmental	Social	Governance	Source
1	*Distribution Planning and Control System (DPCS)*	✓	✓	✓	(Dayanti *et al*., 2020)
2	*Truck Tracking (INDIGO Tracker)*	✓		✓	(Momin *et al*., 2019)
3	Sistem Scheduling Truk Online (SISTRO)	✓		✓	(Setiawan, 2022)
4	*Web-based system*	✓			(Buchanan *et al*., 2021)
5	*Farmer Card and Distribution Information System*		✓	✓	(Harun *et al*., 2021)
6	*Dynamic System Model*	✓	✓		(Pelak *et al*., 2017)
7	*Optimization of Transportation Model*	✓			(Pauli de Bastiani *et al*., 2024)
8	Sistem Distribusi Pupuk Pemerintah			✓	(Aribowo & Emanuel, 2023)
9	*Saving Matrix*	✓		✓	(Pulansari *et al*., 2021)
10	*Linear Programming*	✓			(Pauli de Bastiani *et al*., 2024)
11	*Vehicle Routing Problem*	✓		✓	(Tröster *et al*., 2019)
12	*Fuzzy Goal Programming*	✓			(Rezayi *et al*., 2017)

Environmental Impact of Sustainable Manufacturing

Based on Table 5, it is evident that there are 12 sustainable manufacturing practices widely implemented in the fertilizer distribution process, which have had significant impacts on the environmental aspect. The adoption of the Distribution Planning and Control System (DPCS) allows real-time monitoring of the supply chain from production centers to retail outlets. This system has successfully anticipated fertilizer shortages in various regions and improved distribution efficiency, thus reducing waste and environmental impact due to suboptimal distribution. As a result,

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fertilizer availability for farmers has become more timely and transparent (Dayanti *et al*., 2020).

Additionally, the use of Truck Tracking (INDIGO Tracker) has been implemented to enhance fertilizer distribution efficiency by directly monitoring the location and condition of vehicles. Studies show that this system can reduce fuel consumption and lower carbon emissions from fertilizer transport. By optimizing routes and leveraging technology-based monitoring, the system helps reduce the carbon footprint of distribution (Momin *et al*., 2019).

The implementation of the Online Truck Scheduling System (SISTRO) has also had a positive impact by reducing congestion at warehouses and optimizing fertilizer delivery schedules. Research indicates that digitalizing the scheduling system has reduced wait times and fuel consumption, which directly leads to a reduction in greenhouse gas emissions from the distribution fleet (Setiawan, 2022).

In terms of digitalization, the Web-based System has been used to manage the fertilizer supply chain more efficiently. This system enables more accurate monitoring of stock and demand, reducing waste and ensuring more effective distribution. Research by Buchanan et al. (2022) shows that the use of web-based systems in fertilizer distribution improves logistics efficiency and mitigates environmental impacts caused by uncontrolled distribution. A Dynamic System Model has been developed to simulate various scenarios in fertilizer distribution. This model helps identify more environmentally friendly distribution patterns by optimizing fleet use and reducing resource waste (Pelak *et al*., 2017). Research by Abadi et al. (2021) shows that the application of this model successfully reduced distribution costs and improved fertilizer transportation efficiency. The Optimization of Transportation Model approach has also been applied to reduce energy consumption in fertilizer distribution. Research conducted by Wulandari (2024) using Excel Solver-based optimization shows improvements in demand fulfillment, reductions in distribution costs, and lower fuel consumption, which directly impacts carbon emissions reductions (Pauli de Bastiani *et al*., 2024).

In addition to transportation optimization methods, the Saving Matrix and Linear Programming techniques are also used to determine the best distribution routes that minimize travel distance and fuel consumption. Studies show that this combination of methods can reduce distribution costs by up to 15% while lowering the carbon footprint from operational vehicles in the fertilizer distribution chain (Pulansari *et al*., 2021).

The use of the Vehicle Routing Problem (VRP) in fertilizer distribution has been proven to enhance delivery efficiency and reduce environmental impacts from the transport sector. By utilizing route optimization algorithms, research shows that the VRP method can reduce fuel consumption of distribution vehicles by up to 20%, while ensuring more even fertilizer availability (Tröster *et al*., 2019).

On the other hand, Fuzzy Goal Programming has also been applied in fertilizer distribution management to balance various sustainability factors, including environmental, economic, and social aspects. Studies applying this method show that by considering various sustainable distribution scenarios, energy efficiency can be

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improved without compromising the availability and timeliness of distribution (Rezayi *et al*., 2017).

Impact of Sustainable Manufacturing on Social Aspects

Based on Table 6, there are 10 sustainable manufacturing practices that have been widely implemented in the fertilizer distribution process, yielding significant impacts on social aspects. Research by Dayanti et al. (2020) applied the Distribution Planning and Control System (DPCS) in fertilizer distribution with the aim of reducing the social gap between farmers and fertilizer distribution service providers. This method helps optimize the distribution schedule, thereby reducing delivery delays and enhancing customer satisfaction. By improving distribution management, DPCS not only improves service but also diminishes social inequality, providing more equitable access to fertilizers for farmers in various regions.

Harun et al. (2021) conducted research on the implementation of the Farmers Card program in Rembang Regency, addressing issues related to subsidized fertilizer shortages. By using the Farmers Card, subsidized fertilizer distribution became more controlled, reducing misuse and improving targeting accuracy. The findings indicated that the program increased fertilizer availability for eligible farmers and facilitated smoother transactions for subsidized fertilizers. Furthermore, the Farmers Card also positively impacted equitable access for farmers, reducing the injustices previously experienced by farmers in remote areas. However, challenges remain regarding the technological readiness and the understanding of older farmers, who require additional support and guidance.

Pelak et al. (2017) applied a distribution information system to monitor and manage the fertilizer distribution flow in real-time. By using this system, fertilizer distribution can be monitored more accurately, minimizing delays and distribution errors. The result is that the distribution information system improves communication between distributors and farmers, which increases transparency and accountability in the distribution process. The significant social impact of this system is the reduction in farmer dissatisfaction with fertilizer distribution and an increased sense of justice among them, as they can track the status of their fertilizer shipments.

The use of a dynamic system model to improve fertilizer distribution performance in Mojokerto Regency had a social impact by increasing distribution efficiency, reducing the cost burden on both farmers and the government, and improving farmer access to more affordable fertilizers. The success of this study made an important contribution to social justice by promoting a more equitable and efficient fertilizer distribution system.

Impact of Sustainable Manufacturing on Governance Aspects

Table 6 provides information on seven sustainable manufacturing practices that have been widely implemented in the fertilizer distribution process, yielding significant impacts on governance aspects. Research by X applied the Distribution Planning and Control System (DPCS) in fertilizer distribution to address the frequent shortages that occur in the field. The implementation results show that DPCS can improve the distribution system by providing temporary farmer cards and

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establishing a distribution information system that ensures fertilizers reach eligible farmers according to the RDKK quota (Dayanti et al., 2020). Through tighter monitoring and better coordination between farmers and field officers, fertilizer distribution became more structured and organized. This led to increased transparency and accountability in fertilizer distribution governance, reducing the potential for misuse and enhancing farmers' trust in the distribution system.

Momin et al. (2019) implemented the Truck Tracking (INDIGO Tracker) program to monitor the real-time movement of fertilizer distribution vehicles. This system reduces the potential for delays and schedule mismatches, which directly improves distribution efficiency and reduces transportation costs. By ensuring that vehicles can be accurately tracked, this program has a positive impact on governance by creating a more transparent system and enabling tighter oversight of the distribution process, thus reducing the potential for resource misuse.

Setiawan (2022) applied the Online Truck Scheduling System (SISTRO) to optimize the distribution of subsidized fertilizers from warehouses. SISTRO enables more efficient truck scheduling by minimizing delays and mismatches between planning and actual conditions in the field. This system creates better integration among stakeholders in the distribution process, resulting in reduced transportation costs and fewer mistakes in stock allocation. The social and governance impacts are significant, particularly in the areas of increased transparency, accountability, and the reduction of potential resource misuse.

Harun et al. (2021) implemented the Farmer Card and Distribution Information System to address subsidized fertilizer shortages in Rembang Regency. This program ensures more targeted fertilizer distribution by guaranteeing that only eligible farmers can access fertilizers according to their needs. By introducing the farmer card, the system strengthens distribution governance by providing stricter control over the fertilizer allocation process. The result is a reduction in subsidized fertilizer misuse and an increase in transparency in distribution, fostering greater trust among stakeholders.

Pulansari et al. (2021) implemented the Government Fertilizer Distribution System using the Saving Matrix method to optimize fertilizer distribution routes and reduce transportation costs. By redesigning distribution routes using this method, the research successfully saved travel distance and transportation costs by up to 50% per month. The achieved efficiency contributed to the reduction of resource wastage and improved the effectiveness of fertilizer distribution governance, ensuring timely distribution at lower costs.

Troster et al. (2019) applied the Vehicle Routing Problem (VRP) to further enhance fertilizer distribution efficiency by planning optimal delivery routes. By utilizing the VRP algorithm, the research ensured that distribution vehicles followed the most efficient routes, reducing travel time and avoiding energy waste. This improved resource management, reduced operational costs, and strengthened governance systems for better fertilizer distribution.

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Factors Affecting the Effectiveness of Sustainable Manufacturing in the Distribution Process

The success of sustainable manufacturing in the distribution process is heavily influenced by several key factors that interact with each other. One of the primary factors is operational efficiency. To achieve sustainability, companies need to ensure that the distribution process operates efficiently in terms of time, cost, and resources. The use of advanced technologies, such as integrated supply chain management systems, can minimize waste in the distribution process and increase the speed of product delivery to consumers, thus supporting sustainability efforts.

Energy management is another crucial factor in sustainable distribution processes. Distribution often involves transportation, which requires significant energy, particularly when fossil fuel-powered vehicles are used. The use of environmentally friendly vehicles, such as electric trucks or alternative fuel vehicles, can help reduce carbon emissions and optimize energy use, which is essential for supporting sustainable manufacturing goals (Kuo *et al*., 2022). Therefore, efficient route planning and the utilization of green vehicle technologies become critical elements in achieving sustainability.

Another important factor is the availability and utilization of information technology. The use of information technology to monitor and manage the distribution of fertilizers, goods, or other products in real-time allows companies to identify potential issues and address them promptly (Gedam *et al*., 2021). Systems like the Internet of Things (IoT) or big data analytics enable more accurate inventory and distribution management, which not only reduces waste but also improves service quality to consumers. Furthermore, these technologies can provide valuable insights into consumption patterns and market preferences that are more environmentally friendly.

Stakeholder involvement is another vital factor in the success of sustainable manufacturing. Achieving sustainability in distribution cannot be accomplished solely through internal company policies; collaboration with suppliers, logistics partners, and even consumers is essential (Thirupathi & Vinodh, 2016). Companies that can build strong relationships with all parties in the supply and distribution chain will be more capable of implementing more efficient and environmentally friendly distribution practices. Good stakeholder involvement also ensures that sustainability standards are upheld throughout the distribution chain.

Innovation in product design plays a significant role in the success of sustainable manufacturing, especially in distribution processes. Products designed with transportation ease, environmentally friendly packaging, and efficient material usage in mind will reduce the negative impacts of distribution. For example, products using recyclable packaging or lighter materials can reduce the carbon footprint of the shipping process, thus bringing the company closer to broader sustainability goals.

Additionally, continuous monitoring and evaluation are key to ensuring that each step in the distribution process aligns with sustainability principles. With a structured evaluation mechanism in place, companies can assess the effectiveness of the policies implemented, identify areas that require improvement, and make

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periodic adjustments. Measuring the social, economic, and environmental impact of each stage of distribution helps companies make better decisions and drive more sustainable distribution practices in the long run.

Recommendations for Future Research

Based on the findings of this study, several opportunities for future research can be explored to deepen the understanding of sustainable manufacturing applications in fertilizer distribution. One area that requires further investigation is the optimization of digital technologies, such as blockchain-based systems and artificial intelligence (AI), to enhance supply chain efficiency and transparency in fertilizer distribution. In-depth studies on the implementation of these technologies could provide comprehensive insights into how digitalization can reduce inefficiencies in distribution, prevent misuse of subsidized fertilizers, and improve the accuracy of fertilizer allocation to farmers in need.

Additionally, future research could focus on the impact of government policies on the effectiveness of implementing sustainable manufacturing in the fertilizer industry. A comparative analysis of various policies implemented in countries with different fertilizer distribution systems could offer valuable understanding of which policies are most effective in supporting sustainability. This research could also explore how fiscal incentives, subsidies for environmentally friendly technologies, and related regulations contribute to improving fertilizer distribution efficiency while reducing the negative environmental impacts.

The social aspect is another important dimension that warrants further investigation, particularly concerning the impact of sustainable fertilizer distribution on the welfare of farmers and local communities. This research could include evaluations of farmer involvement in the distribution process, their access to more efficient and environmentally friendly fertilizers, and the socio-economic effects of sustainability. Using case study approaches or survey methods, the research could explore the challenges faced by farmers in adopting sustainable fertilizers and how policy interventions can improve these conditions.

Furthermore, future studies could adopt a more in-depth quantitative approach through predictive models and simulations to analyze optimal scenarios in sustainable fertilizer distribution. The use of optimization models based on machine learning or dynamic systems could help understand the interactions between various variables, such as logistics costs, environmental impacts, and the level of technology adoption by the industry and farmers. As a result, this research could contribute to the development of more efficient, sustainable, and environmentally-oriented fertilizer distribution strategies that also strengthen national food security.

CONCLUSION AND SUGGESTION

1. The bibliometric analysis reveals a significant increase in research related to sustainable manufacturing in fertilizer distribution during the 2015-2024 period. The number of publications on this topic rose from only 2 articles in 2015 to 56 articles in 2024, indicating an annual growth trend of 9.6%.

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However, research still predominantly focuses on fertilizer production rather than distribution, as evidenced by the dominance of keywords such as "fertilizer" (27 occurrences), "nitrogen" (30 occurrences), and "phosphorus" (30 occurrences). Geographically, China leads in the number of publications (101 articles), followed by Brazil (31), Italy (23), and the United States (22). This rising trend in research underscores that sustainable fertilizer distribution is gaining global attention, although there remains a gap in exploring its distribution aspects.

2. Sustainable manufacturing has a positive impact on the environmental, social, and governance aspects. Environmentally, the application of technologies such as the Distribution Planning and Control System (DPCS) and Truck Tracking (INDIGO Tracker) helps reduce fuel consumption and carbon emissions in fertilizer transportation. Socially, innovations like the Farmers Card improve equitable access to fertilizer for farmers, reduce social disparities, and enhance the accountability of distribution. In terms of governance, the digitalization of distribution systems and data-based monitoring increases transparency, prevents the misuse of subsidized fertilizers, and strengthens coordination among stakeholders.
3. The effectiveness of sustainable manufacturing in fertilizer distribution is influenced by several key factors, including the readiness of information technology and digitalization, operational logistics efficiency, stakeholder involvement, and support from regulations and government policies. The implementation of technology-based supply chain management systems allows for more efficient and environmentally friendly distribution management. Additionally, the success of distribution depends on innovations in product design, optimization of transportation routes, and continuous evaluation and monitoring.
4. Future research opportunities include optimizing the use of digital technologies such as blockchain and artificial intelligence (AI) in fertilizer distribution systems, analyzing the impact of government policies on the sustainability of the fertilizer supply chain, and conducting comparative studies on the effectiveness of various sustainable fertilizer distribution models in different countries. Additionally, further research is needed on farmer involvement in sustainable fertilizer distribution systems, as well as machine learning-based simulation models to optimize fertilizer distribution efficiently and with an environmental focus.

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