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► **To cite this version:**

Ahmad Rezae Elyatoo, Maria Di Mascolo, Abdourahim Sylla. Bibliometric Analysis on the Application of Quantitative Decision-Aiding Methods to the Decarbonization of Manufacturing Processes. 2025 IEEE/IFAC/DBLP International Conference on Control, Automation and Diagnosis (ICCAD'25), Jul 2025, Barcelona (ES), Spain. <10.1109/ICCAD64771.2025>. <hal-05216999>

HAL Id: hal-05216999

<https://hal.science/hal-05216999v1>

Submitted on 20 Aug 2025

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Bibliometric Analysis on the Application of Quantitative Decision-Aiding Methods to the Decarbonization of Manufacturing Processes

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Abstract—Decarbonization has become a crucial imperative in the industrial sector due to its significant contribution to global greenhouse gas (GHG) emissions. This study conducts a comprehensive bibliometric analysis of academic research on decarbonization in manufacturing processes and operations management. Using a systematic literature review approach, 105 relevant papers were identified from an initial pool of 8,032 publications retrieved from the Web of Science database. The analysis categorizes research contributions based on key operations management topics, like production planning, production scheduling, process design, and inventory management, while also examining the main decarbonization focus, such as carbon reduction, energy reduction, waste reduction, and the predominant quantitative decision-aiding methods. Findings reveal that production planning is the most extensively studied area, with many papers directly considering carbon reduction, while methods such as mathematical modeling dominate decision-aiding methods. The study also identifies research gaps, particularly the underutilization of machine learning and multi-criteria decision-making (MCDM) in decarbonization efforts and offers recommendations for futures research.

Keywords— *Sustainable Manufacturing, Decarbonization, Industrial processes, Operations Management, Decision-aiding method, Bibliometric Analysis*

I. INTRODUCTION

Among the major sources of global carbon, the industrial manufacturing segment is one of the highest priority areas requiring intervention [1]. The industrial processes—raw material extraction, product design, manufacturing, and product delivery—are major sources of GHG emissions. The automotive, machinery, and steel industries are some examples of such industries, and it shows the need to introduce innovative carbon reduction strategies in global value chains. Thus, the employment of green manufacturing practices and the

introduction of Green Supply Chain Management (GSCM) practices are gaining prominence [2]. The strategies are centered around the integration of environmental issues into mainstream operational issues, promoting efficiency and reducing the involved costs, time, and carbon emissions [3], [4].

Governmental policies play a significant role in driving decarbonization in industries by enforcing regulations and economic incentives [2], [5]. Among the tools used by the policies are carbon taxation, cap-and-trade mechanisms, and carbon labeling. Also, consumer-driven mechanisms, such as carbon labeling, enhance transparency and shift demand to low-carbon products, driving the collective responsibility among industries and consumers in the realization of the low-carbon economy.

In parallel to regulation and industrious effort, academic research also helped build decision-support tools and strategy frameworks to inform industrial processes decarbonization. As the research corpus in this domain expands, bibliometrics provides a useful tool to aggregate research progress, monitor leading publishers, and suggest future trends. Through the analysis of publication patterns, bibliometrics research is able to monitor the course of decarbonization research, and inform future research directions. To the best of our knowledge, there is no literature review study focusing on decarbonization efforts in manufacturing processes.

This study aims to conduct a bibliometric analysis of the academic research in the domain of manufacturing processes decarbonization, gaining a detailed insight into the leading journals and conferences, topic evolutions, and major research trends. Through the integration of the available body of research, this study offers greater insight into how academic research contributed to the strategies in decarbonizing manufacturing processes and offers recommendations for future research.

The remainder of this paper is structured as follows: We first give the research methodology, in Section 2, then the results of the bibliometric analysis, in Section 3, before a conclusion, identifying the research gaps, in Section 4.

II. RESEARCH METHODOLOGY

To conduct this bibliographic analysis, a systematic search was performed on April 20th of 2024 in the “Web Of Science (WOS)” database using the keyword string “(decarbon* OR carbon OR CO₂) AND (manufacturing OR production OR industr*)”. The search was carried out in the titles of the articles only and the following WOS categories were considered: Environmental Sciences, Engineering Manufacturing, Green Sustainable Science Technology, Engineering Environmental, Environmental Studies, Engineering Industrial, Operations Research Management Science, Management, Computer Science Interdisciplinary Applications, Computer Science Artificial Intelligence, Computer Science Information Systems and Computer Science Software Engineering. This search yielded 8,032 papers, which were then subjected to a rigorous screening process to ensure relevance to the field of “industrial engineering, operations management, and manufacturing”.

A. Title and Abstract Screening

Papers that did not focus on “industrial processes, operations management, or manufacturing systems” were excluded. Research primarily related to the “building industry, materials engineering, and energy production” was removed. Studies that did not specifically address “Carbon emissions” were discarded. Generic contributions, such as “comparative studies at national or international levels”, were excluded due to their lack of methodological depth in decision-making within manufacturing contexts. After this phase, 261 papers were retained for full-text review.

B. Full-Text Review

Additional papers were found to be out of scope, particularly those focusing on: geographical analyses of industrial carbon emissions (e.g., national or regional-level studies), general policy guidelines without quantitative decision-aiding methods, and technical process analyses, like LCA method, that do not incorporate operations management. After this thorough examination, a final set of 105 papers was identified as directly relevant. These papers predominantly focus on decarbonization of manufacturing processes and industrial operations using quantitative decision-aiding methods. The findings from the bibliometric analysis presented in the next section provide insight into methodological trends, research gaps, and future directions for decision-aiding in CO₂ reduction in manufacturing processes.

III. RESULT OF BIBLIOMETRIC ANALYSIS

A. Publication per year

The Figure 1 depicts trends in publication numbers for the range of timespans. There can be three phases regarding publication frequency in the information.

Early Period (2011–2014): Publications remained relatively low, with a mean of 1 annual publication. Journal and conference articles in these years were not common, indicative

of a new and developing period of activity in terms of research, possibly with limited publication channels.

Growth Period (2015–2022): There is a significant increase in publication, with an average of 9.25 articles a year. There is a span of heightened activity in terms of studies, with a significant increase in articles in literature. There is a fluctuation in conference articles, reflective of activity variation in conference platforms over the years.

Recent Surge (2023–2024): There is a significant increase in publication, with 20 journal articles in 2023 indicative of a notable surge in output in terms of research work. Also, for 2024 there are 7 papers for the first 4 months.

Generally, the chart reflects an overall increasing trend in the field; it is important to note that the bar representing 2024 accounts for only one third of the year.

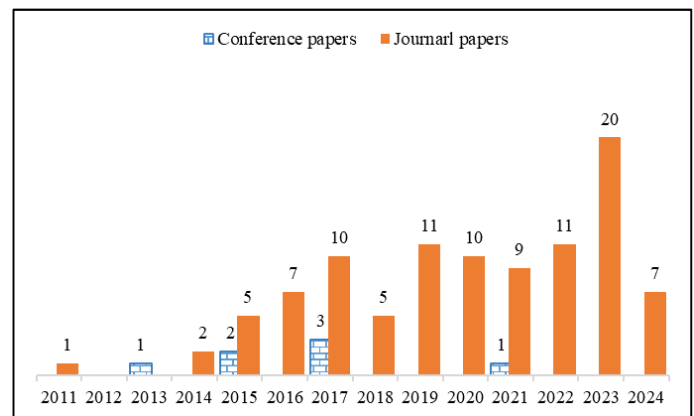


Figure 1- Publication in years

B. Publication per journal

The leading publisher is Journal of Cleaner Production, with 35% of overall publication; in its wake, Computers & Industrial Engineering (9%) and Sustainability (8%) follow. All three together contribute 52% of overall publication, a demonstration of their high position in the field (Table 1).

Table 1 – Journal participation

Type	Journal Name	No of papers	percentage
Journal	Journal Of Cleaner Production	37	35%
	Computers & Industrial Engineering	10	9%
	Sustainability	9	8%
	International Journal Of Production Research	5	5%
	Applied Sciences-Basel	3	3%
	International Journal Of Advanced Manufacturing Technology	2	2%
	Process Integration And Optimization For Sustainability	2	2%
	Rairo-Operations Research	2	2%
	Other Journals	29	27%
Conference	Conferences	7	7%

Five other journals, including International Journal of Production Research, Applied Sciences-Basel, International Journal of Advanced Manufacturing Technology, Process

Integration and Optimization for Sustainability, and Rairo-Operations Research, generated between 2% and 5% of total publication output. All five, together with the first three, make 66% of overall publication output, with a high degree of concentration in a small group of sources.

The row Other Journals, in Table 1, includes 29 additional journals, each with only one paper, collectively contributing 27% of the publications, suggesting a broad but less frequent distribution of research across multiple outlets. Similarly, the row Conferences account for 7%. The data suggests a strong preference for journal publications over conference proceedings, with journals comprising 93% of the total publications.

Table 2 - Country Participation

Country	No of papers	Percentage
China	59	53%
India	13	12%
Taiwan	8	7%
USA	6	5%
France	5	5%
Canada	3	3%
Hong Kong	3	3%
Iran	3	3%
Other Countries	11	10%

C. Publication per country

Geographic distribution of the 105 selected papers shows that 53% of the papers' corresponding author are from China (Table 2). Next is India with 12% of the publications reflecting the growing interest of authors in this country. Taiwan (7%), the USA (5%), France (5%), Hong Kong (3%), and Iran (3%) are the other major contributors. The group "Other Countries" collectively accounts for 10% of the publications with individual countries accounting for less than 1%. This means while the studies are spread out around the world, most are concentrated within a few leading countries.

D. Decarbonization focus

The Figure 2 groups research articles according to their dominant decarbonization theme. The most important areas discussed include carbon reduction, energy reduction, and waste reduction.

1. Carbon Reduction

Carbon reduction is the most extensively studied aspect of decarbonization, appearing in 99 papers. The methodologies in these studies generally fall into two broad categories, Simplified Approach and Detailed Process-Level Approach. In Simplified Approach papers apply a generalized carbon emission coefficient to products, estimating carbon emissions at an aggregate level (e.g., [6], [7], [8]). In the Detailed Process-Level Approach, studies incorporate carbon emission coefficients for various stages of production, such as raw material processing, fuel consumption, electricity usage, and other operational aspects (e.g., [9], [10]).

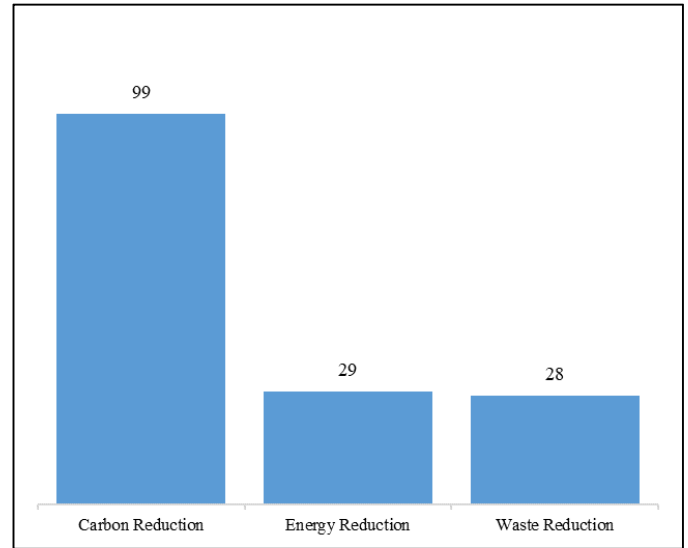


Figure 2- Decarbonization focus

Among these 99 papers, 54 studies focus exclusively on carbon reduction as the primary decarbonization strategy (e.g., [11], [12]) while 45 papers examine carbon reduction in conjunction with other decarbonization strategies (e.g., [13], [14]).

2. Energy Reduction and Waste Reduction

Studies focusing on energy reduction predominantly address electricity consumption in manufacturing processes. These papers explore strategies for minimizing energy and model it as minimization of energy or cost of energy (e.g., [15], [16]). There are two main ways to consider energy reduction in a mathematical modeling, adding to objective function or considering as a constraint.

Research on waste reduction primarily investigates remanufacturing initiatives (e.g., [17], [18]). In modeling approach, considering GHG emission of new and remanufactured products at the same time or forcing the manufacturer to collect end of life products are some examples of waste reduction considerations. Another issue in this field is considering the role of quality of remanufactured product on decision making and customer behaviors.

E. Main quantitative decision-aiding methods

An analysis of the methodologies used in manufacturing processes decarbonization highlights a strong interest for mathematical modeling and mathematical equations, which are utilized in 48 and 43 papers, respectively (Figure 3). These approaches form the backbone of quantitative research in this domain, enabling precise representation and optimization of decarbonization strategies (e.g., [19], [20], [21]).

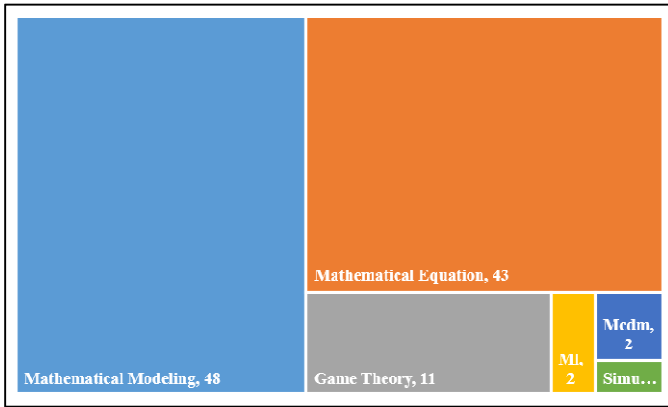


Figure 3- Decision aiding methods

Other methodological approaches receive significantly less attention: Game theory (11 papers) is employed to model competitive interactions in markets or supply chains where multiple stakeholders aim to optimize both economic and environmental objectives (e.g., [22], [23]). Machine learning (ML) (2 papers) and multi-criteria decision-making (MCDM) (2 papers) are rarely applied (e.g., [24], [25]), despite their potential for handling complex, data-driven sustainability challenges. Simulation (1 paper) is the least utilized approach, suggesting an underexplored opportunity to model real-world decarbonization scenarios dynamically [26].

The prominence of mathematical modeling and equations suggests that research in this field heavily relies on structured, model-based frameworks, rather than data-driven approaches. The limited use of machine learning (ML in Figure 3), MCDM, and simulation (Simu in Figure 3) indicates a research gap. Given the increasing availability of data and computational resources, integrating these techniques could enhance predictive accuracy and decision-making efficiency in decarbonization efforts. Future research could benefit from combining traditional mathematical models with advanced AI techniques to improve adaptability and real-time decision-making in sustainable production systems or developing multi-criteria decision-making (MCDM) methods in decarbonization efforts.

F. Manufacturing and operations management topics

The analysis of publications in Figure 4 in this field reveals that production planning is the most extensively studied topic, with 78 papers incorporating decarbonization considerations within production planning strategies (e.g., [27], [28]). This highlights the central role of production planning in achieving sustainability goals by optimizing resource allocation, reducing emissions, and enhancing operational efficiency.

Following production planning, process design/technology selection emerges as the second most researched topic, appearing in 23 papers (e.g., [29], [30]). This indicates a significant interest in exploring advanced and cleaner manufacturing techniques to mitigate environmental impact.

Other research areas receive comparatively less attention: Inventory management (17 papers) [31], and product pricing (13 papers) [32], reflect the growing recognition of supply chain and economic factors in CO2 reduction in manufacturing processes. Scheduling (10 papers) plays a role in optimizing production

timelines to minimize energy consumption and CO2 emissions [4]. Process/machine parameter optimization (7 papers) [33], product design (5 papers) [34], and maintenance planning (3 papers) [35] are the least frequently studied topics in the setting of quantitative decision-aiding methods as defined in this article, suggesting potential gaps in research despite their relevance to decarbonization.

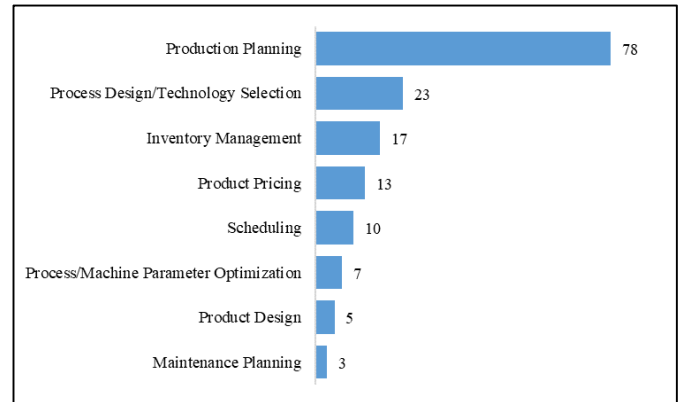


Figure 4- Manufacturing and operations management topics

The relatively low number of studies on product design, process/machine parameter optimization, and maintenance planning suggests opportunities for further exploration. These areas are crucial for long-term sustainability, particularly in improving product lifecycle management and enhancing machine efficiency to reduce emissions. The dominance of production planning in manufacturing processes decarbonization research highlights its importance in balancing economic and environmental objectives. Future research may explore how production planning interacts with other factors, to achieve comprehensive manufacturing processes decarbonization.

IV. DISCUSSION

On the one hand, bibliometric analysis could be valuable for academic researchers to identify the scientific gaps, whether by research field (e.g. production planning) or by method (e.g. simulation). On the other hand, practitioners could also benefit as well. Research interest trends may show the potential future competitive advantages and changes in customers' priorities. Figure 1 shows the growing interest in decarbonization practices in industries.

In addition, the large number of papers in production planning shown in Figure 4 demonstrates the maturity of the field and its applicability to real-world implementations. Extensive literature on production planning could be due to many well-established theories for solving production planning problems such as mathematical programming for modeling and metaheuristic or commercial solvers for solving it. In addition, this problem does not need detailed historical data about energy or CO2. In addition, dealing with production planning is one of the most common operations management activities in manufacturing companies.

We have a few papers for product design because this problem is not generally solved with the methods in the scope of this study (see Figure 3). For example, since we do not consider

LCA methods, we do not have a lot of relative papers. Also, the limited number of research papers on maintenance could be explained by our search query which does not explicitly consider maintenance as a key word. Although product pricing is not a decarbonization effort or an operations management problem, we study it in our analysis since in some papers it is mentioned beside other objectives and has an effect on other decisions, especially in papers in which the game theory approach is the main approach.

Regarding the research gaps, one important identified research gap is the absence of the application of machine learning and other data-driven methods to manufacturing processes decarbonization. The limited usage of ML methods may be due to a lack of detailed historical data, since the decarbonization monitoring is still a relatively new field, and the GHG emission data are still rare. Therefore, to deal with this challenge, manufacturing industries should install relative sensors and adopt the data collecting systems to provide sufficient energy or GHG emission data. Also, researchers should work on the development and application of energy-efficient AI tools.

V. CONCLUSION

This study encompasses the decarbonization of manufacturing processes and presents a comprehensive bibliometric analysis of the field. The findings demonstrate a rapidly increasing literature base, particularly since 2023, suggesting increasing momentum and scholarly interest. There is also a pronounced regional clustering, with most contributions originating from Asian countries.

The analysis indicates that research output is extremely concentrated in a small number of journals. In terms of research focus, over half of the papers deal solely with the carbon emissions coefficient and not with other coefficients. Methodologically, mathematical modeling and equations remain the most common decision-aiding methods. Additionally, production planning has been the predominant problem in manufacturing processes decarbonization research.

Future research for this bibliometric analysis study could entail LCA-focused studies to provide a more complete image of decarbonization across the entire value chain. More cross-sectional analyses are also needed to examine under-researched intersections between different research streams and to ascertain new opportunities for interdisciplinary collaboration.

ACKNOWLEDGMENT

This work was supported by a French government grant managed by the Agence Nationale de la Recherche (ANR) under the France 2030 program: PEPR Spleen's DCARBO project, reference 22-PESP-0002.

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