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# A Comprehensive Review of Sustainable Manufacturing Practices

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## Abstract

The challenging issues of pollution, waste disposal, loss of biodiversity, resource depletion, environmental degradation, and climate change are directly driving up demand for sustainable manufacturing. Manufacturers face tremendous pressure to implement eco-friendly production practices due to government regulations and the rising expectations of stakeholders.

As a result, research on sustainable manufacturing has significantly increased, leading to numerous innovative ideas. T his literature review intends to thoroughly examine a broad range of sustainable manufacturing practices (SMP) and explores the critical enablers that drive the adoption of SMP. Conversely, it identifies the significant barriers that impede the widespread adoption of sustainable manufacturing practices. Furthermore, the review scrutinizes the role of government regulations in shaping the landscape of SMP, analysing their effectiveness in promoting sustainable practices. For this study 234 articles were meticulously selected from the online database, spanning the period from 1994 to 2024. The publishing year, publisher, journal, country, number of citations, industry focus, research methodology, sustainability dimensions, and study topics were all taken into consideration while classifying these publications. The study's key findings highlight the importance of balancing economic, environmental, and social concerns (the Triple Bottom Line) within sustainable manufacturing practices, exploring various theoretical frameworks to understand why companies choose sustainable manufacturing practices. The research also emphasizes the significant impact of government rules and regulations, and it discusses the difficulties and potential benefits for industries shifting to more environmentally friendly production.

***Keywords:*** - Sustainable manufacturing practices, sustainable production practices, sustainability, sustainable development

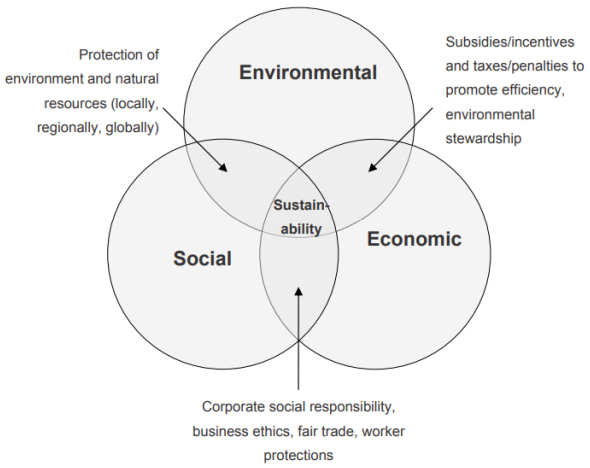
## 1. Introduction

The manufacturing sector significantly contributes to greenhouse gas emissions and environmental deterioration, as highlighted by international assessments such as the “Report of the United Nations Environment Assembly of the United Nations Environment Programme 2019” and the Intergovernmental Panel on Climate Change (IPCC) (Calvin et al., 2023). In order to reduce the effects of climate change, these reports emphasize the urgent need for revolutionary changes in manufacturing processes. As such, sustainable manufacturing—which includes low-carbon operations, waste reduction, and resource efficiency—has become more and more important as a strategic necessity. Industries may lower their environmental impact and increase their competitiveness and resilience in a changing climate by incorporating sustainable practices into their manufacturing systems (UN Environment Progamm, 2024).

Sustainability was clearly developed and expressed for the first time in 1987 within the Brundtland Report, commissioned by 'United Nations World Commission on Environment and Development' as "meeting the needs of the present without compromising the ability of future generations to meet their own needs.". Sustainable Manufacturing contributes to growth and development, as discussed in the Brundtland Report's "Sustainable Development" section, which emphases on "meeting the needs of the current generation without compromising those of future generations(Yuan & Zhang, 2013)". There have been several new definitions of sustainability and sustainable development proposed since the publication of the Brundtland Report. Moldavska & Welo, (2017) identified a total of 89 different definitions for sustainable manufacturing. These definitions underscored the importance of sustainable production, examining both the drivers and obstacles to its implementation. In 2000, the United Nations (UN) introduced the Millennium Development Goals, seeking to create a more equitable, sustainable, and prosperous world. Though, these goals were not attained by 2015. United Nations implemented a new set of goals in 2016, the Sustainable Development Goals, which are wider and more determined, targeting to produce a better and more sustainable future by 2030 . The Seventeen Sustainable Development Goals (SDGs) are a set of interrelated and mutually dependent objectives that aiming to achieve human welfare, economic prosperity, and environmental safety simultaneously. The progress to one goal can supportively impact progress to others, there may also be trade-offs and conflicts between the goals, leading to potentially diverging or contradictory outcomes (Allison et al., 2013). Responsible production and consumption are considered as 12$^{th}$ of the Sustainable Development Goals (SDGs), highlighting the importance of sustainable manufacturing as a crucial pathway towards sustainable development.

Sustainable manufacturing practices (SMP) are the practices adopted by the firms to protect the nature and improve the social welfare throughout the production (Hami et al., 2015., Ibrahim et al., 2019). SMPs are methods used by the manufacturing sectors to efficiently utilize the natural resources in order to meet social, economic, and environmental sustainability (Abdullah et al., 2023). Kofi Opoku et al., (2023) states that SMPs take into account the social, environmental, and economic aspects of production processes. These practices help the preservation of natural resources and energy, encourage inventory control, reduce lead times, and improve product specifications, stakeholder engagement, the customer satisfaction, and public safety. Manufacturing industries should accomplish a balance between economic, environmental, and social factors to ensure their continued presence in the market. Sustainable Manufacturing has emerged as a valuable approach that facilitates this balance among these three critical aspects(Malek & Desai, 2020). The implementation of sustainable manufacturing practices (SMPs) is strongly supported by the theory of constraints (TOC), which posits that SMPs support in overcoming limitations that hinder a organization's ability to achieve sustainable performance outcomes (Şimşit et al., 2014).

By adopting SMP and transparently reporting their sustainability efforts, firms can simultaneously enhance their financial performance, contribute to the United Nations Sustainable Development Goals, and gain recognition within sustainability indices (Khan et al., 2021). In the past, sustainability just meant protecting the environment, but the current literature places emphasis on three pillars of sustainability: environment, society, and the economy (Purvis et al., 2019) as shown in Figure 1 (Rosen & Kishawy, 2012). Studies by (Garetti & Taisch, 2012) highlight technology and education as two key enablers for achieving sustainability across all three pillars: environment, society, and economy. The pillars of sustainability are inseparable and mutually dependent. However, the relative importance of the economic, environmental, and social dimensions of sustainability can vary depending on the specific context and criteria being used (Bhanot et al., 2017). Without sustainable manufacturing practices, achieving sustainability and sustainable development becomes significantly more challenging.




The objective of the study is to answer the following research questions:

**Figure 1:** Sustainable Manufacturing and Design: Concepts, Practices and Needs (Rosen, M. A., & Kishawy, H. A. (2012)

1. Which sustainable manufacturing practices have been most researched and implemented?
2. What are the primary drivers and barriers to the acceptance of sustainable manufacturing practices within industries?
3. What is the impact of governmental policies and regulations on the execution of these practices?

The paper is organised as follows. First, a comprehensive literature review is conducted to examine existing research on sustainable manufacturing practices. This is followed by a theoretical foundation that explores the underlying theories related to sustainable manufacturing. Subsequently, the methods and materials used for the study are detailed, outlining the research methodology and data collection techniques employed. A concise summary of the literature review is then presented, highlighting the main findings and insights from previous research. Finally, the paper concludes with a summary of the key findings and recommendations for future research, identifying potential areas for further exploration and development in the field of sustainable manufacturing.

## 2. Summary of the Literature

Existing research on sustainable manufacturing typically adopts a fragmented approach, focusing either on its variables or performance metrics (Despeisse et al., 2012;Abdul-Rashid, Sakundarini, Raja Ghazilla, et al., 2017). Some, studies have examined the drivers and barriers hindering sustainable manufacturing adoption (Nordin, Ashari, & Hassan, 2014) and the role of policies and regulations (Chourasiya et al., 2023). This review investigates the existing literature on sustainable manufacturing practices. It aims to identify the most widely researched and implemented practices, as well as the primary factors driving and hindering their adoption within industries. Additionally, the study investigate the impact of governmental policies and regulations on the execution of sustainble manufacturing practices. By examining these aspects, this research seeks to contribute to understanding of the current state of sustainable manufacturing and to inform strategies for promoting its wider adoption.

### 2.1 Concept of sustainable manufacturing

The idea of sustainable manufacturing emerged at the 1992 UN Conference on Environment and Development. Sustainable manufacturing, as defined by the International Trade Administration (2007), aims to create products "that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound". It represents a convergence of lean, green, six sigma, and socially responsible practices (Hariyani & Mishra, 2022). To improve organizational sustainable production, numerous business improvement techniques have been introduced over time, including Total Quality Management,

Business Process Re-engineering, Just-In-Time, Lean, Agility, and Six Sigma (Thomas et al., 2012). The 6Rs framework (reduce, reuse, recycle, recover, remanufacture, and redesign), helps conserve resources and reduces environmental impact (Govindan et al., 2013). Sustainable manufacturing try to minimize the negative environmental impacts associated with products and processes (Malek & Desai, 2020) and acts as a foundation for organizations to achieve a Triple Bottom Line (TBL), encompassing social well-being, ecological health, and economic prosperity (S. Ahmad et al., 2023). Sustainable manufacturing involves strategically optimizing production processes to reduce the environmental impact, conserve natural resources, and assure the safety of workers, communities, and consumers. This approach entails the intelligent utilization of natural resources during production simultaneously reducing waste, emissions, and energy consumption (Garetti & Taisch, 2012). Ultimately, sustainable manufacturing seeks to balance economic prosperity with environmental stewardship and social responsibility (Rosen & Kishawy, 2012).

### 2.2 Theoretical Foundations of Sustainable Manufacturing

A comprehensive understanding of sustainable manufacturing requires exploring various theoretical perspectives**.** This section outlines key theoretical frameworks that underpin environmentally and socially responsible manufacturing practices.

**The resource-based view of the firm (RBV)** is a theoretical framework positing that companies can attain a competitive advantage by nurturing and leveraging their distinctive resources and capabilities. Introduced by Jay Barney in 1991, RBV contends that 'firms possessing resources that are valuable, rare, inimitable, and non-substitutable' (VRIN) are better positioned to outperform their rivals. Resources are deemed valuable when they enable a company to capitalize on opportunities and/or mitigate threats in its external environment. Rare resources are those which are not owned by many other firms. Inimitable resources are those that are difficult to copy. Non-substitutable resources cannot be replaced by other resources. Colette Darcy, Jimmy Hill, (2014) applied this theory to Small and Medium Enterprises to help them to identify and develop resources that will give them a competitive edge. The RBV allows firms to look at their business from a different perspective that focuses on their internal strengths and weaknesses. This can help them to recognize areas where they can improve their operation, such as by capitalizing in new technologies or training their employees. The natural-resource-based view (NRBV) of the firm, argues that firms can gain a competitive advantage by utilizing their unique resources and competences. The unique resource or capability is the ability to adopt sustainable manufacturing practices (Aboelmaged, 2018).

**Institutional theory** describes why organizations, particularly in the same industry, often share similar characteristics. This is a sociological perspective that explores how organizations implement and sustain certain practices aligned with the expectations of their surrounding environment. This theory help for analyzing the pressures that influence a company's sustainability practices and based on these pressures, organizations may adopt various strategies (Iarossi et al., 2012). They are constantly being formed by institutional pressures, including government regulations, societal norms, and professional standards. These pressures can lead to what's called isomorphism – the tendency for organizations in the same field to become more alike over time. DiMaggio and Powell, (1983) identified three key drivers of this process: coercive, normative, and mimetic isomorphism. Coercive isomorphism arises from external pressures, normative isomorphism stems from standardization and the shared norms, mimetic isomorphism occurs when organizations imitate the practices from other organizations. The collective outcome of these three forces can be significant and driving organizations to adopt sustainable manufacturing practices (Shubham et al., 2018). Institutional theory is a valuable tool for understanding the motivations behind sustainable manufacturing practices. By understanding the different types of institutional pressures, organizations can make informed decisions about whether or not to adopt sustainable practices (Dubey, Gunasekaran, Sushil, et al., 2015)

**Stakeholder theory** is important for understanding how organizations can influence consumer behavior through green manufacturing practices. Stakeholders are any individual or group who is affected, either directly or indirectly, by the activities of an organization, whether internally or externally. Organizations can influence consumer behavior by

adopting sustainable manufacturing practices and involving stakeholders in the creation, development, and execution of these practices. This theory recommends that firms should consider the interests of all stakeholders and the environment, to maximize profits (Freeman, 2001). He argues that firms that want to conduct successful business must consider the views and expectations of their stakeholders. This is because stakeholders have the power to affect the success of the firm, either negatively or positively.

**Theory of Planned Behavior (TPB)** explains how someone's intention to perform a specific action is influenced by three key factors: their attitude toward the action, their perception of social norms regarding the action, and their perceived behavioral control. Theory of planned behaviour is a strong predictor of various pro-environmental activities like recycling, energy saving, waste management and disposal, and sustainable transportation methods. The TPB framework helps to identify the factors like attitudes, subjective norms, and perceived behavioral control that shape these intentions (De Groot & Steg, 2007).

**Herzberg's two actor theory of motivation** describes that organizations need to consider both internal and external (intrinsic and extrinsic) factors to make a motivated workforce. By ensuring safe working conditions and encouraging personal growth, organizations can enhance employee satisfaction and productivity, which supports environmental manufacturing practices. Overall, Herzberg's two-factor theory propose a framework for understanding the effects of social impacts on worker motivation and organizational performance in the manufacturing sector (Gbededo & Liyanage, 2018).

## 3. Methods and Materials

Literature reviews present an in-depth overview of various research initiatives as well as a historical perspective of the subject of study (Cosimato & Vona, 2021). The “systematic” or “structured” literature review is a valuable strategy for searching, comparing, analysing and summarising existing research. . The SLR methodologies include problem definition, protocol development, search of literature, screening, quality assessment, data extraction, analysis, synthesis, and results reporting (Xiao & Watson, 2019). This literature review examined research articles published from 1994 to 2024, from: Google Scholar, ScienceDirect, Ebsco and Scopus. A list of keywords was established for research purposes, including: (1) sustainable manufacturing practices, (2) sustainable production practices, (3) sustainability, (4) sustainable development. To identify relevant contributions that included keywords, an initial screening based on abstract analysis was conducted, as shown in Figure 2. Applying predefined delimitation criteria eliminated papers that did not align with the study's objectives (Table 1). To ensure the quality of the study, only peer-reviewed articles published in English with at least one keyword in the title or abstract were considered.

**Table 1.** Delimitation criteria

| | |
|---|---|
| Time | Paper published up to the 2024 |
| Search area | Title, abstract, keywords |
| Document | Scientific papers |
| Source | Peer-reviewed journals |
| Language | English |

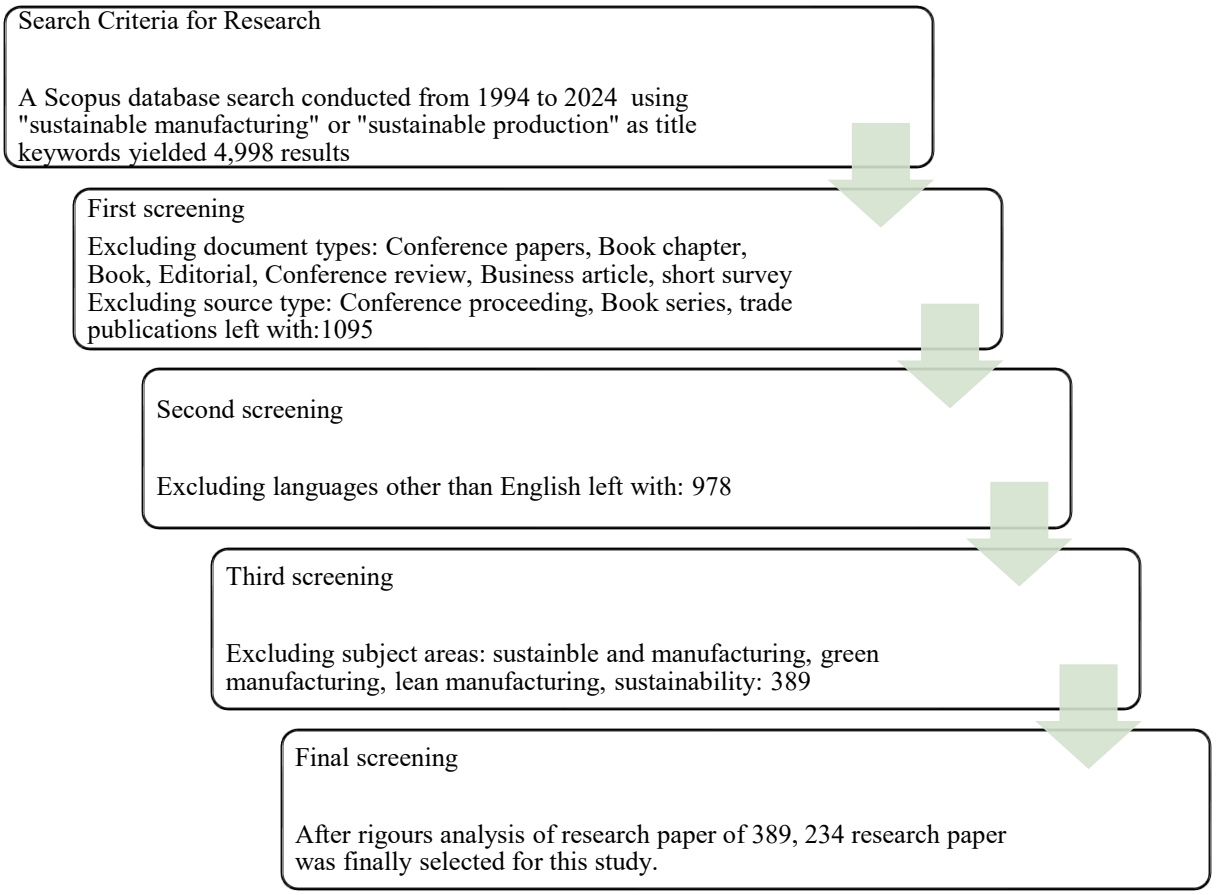



**Figure 2**: Selection criteria

The retained papers were systematically organized into a matrix based on publication year, topic, methodology, journal, and country of origin for in-depth analysis. Initially, 1095 papers were obtained from the database. Following a thorough screening procedure, 306 articles were considered for further review. Out of these, 72 were found via cross-referencing, while the remaining 234 have been identified by hand searches.

Following the methodology demonstrated by Chourasiya et al., (2023) a meticulous categorization and in-depth analysis of the existing review of literature on sustainable manufacturing was undertaken to comprehensively understand the current state of knowledge within the field (Table 2).Table 2: Detailed analysis of some existing review of literature on sustainable manufacturing

| Sl. No | Title | Authors | Publication | Objective | No. of papers Reviewed for the study | Methodology | Result |
|---|---|---|---|---|---|---|---|
| 1 | A Review of Engineering Research in Sustainable Manufacturing | Haapala et al., (2013) | Journal of Manufacturing Science and Engineering | The study aims to emphasize the significance of creating metrics for assessing sustainability performance, | 41 | Comprehensive review of existing literature | The study highlights the necessity for integrated frameworks that enable the assessment of sustainability |

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| | | | | comprehending the interconnections among the three pillars of sustainability —environment, society, and economy—and tackling the challenges and opportunities associated with achieving sustainable manufacturing objectives. | | | metrics at various levels of manufacturing processes and systems. |
| 2 | Status of sustainable manufacturing practices: literature review and trends of triple bottom-line-based sustainability assessment methodologies | S. Ahmad et al., (2023) | Environmental Science and Pollution Research | The study seeks to fill research gaps by examining different aspects of sustainability assessment tools, including the dimensions and indicators utilized, the type of tools (whether integrated or dedicated), the incorporation of weighted indicators, the origins of these indicators, the extent | 102 | To achieve the article's objective, recent SA methods and tools were analysed through an extensive literature review of books, journal articles, and conference papers across databases like Emerald, Science Direct, IEEE Xplore, Springer, Taylor & Francis, Sage, Scopus, and Wiley, given the broad scope of sustainable manufacturing. | Sustainable manufacturing goals can be more successfully attained by employing assessment and reassessment methods that align with the triple bottom line (TBL) concept of sustainability. |

Table 2: Detailed analysis of some existing review of literature on sustainable manufacturing

| Sl. No | Title | Authors | Publication | Objective | No. of papers Reviewed for the study | Methodology | Result |
|---|---|---|---|---|---|---|---|
| 3 | Sustainable manufacturing adoption in textile industries: A systematic state-of-art literature review and future research outline | hourasiya et al., (2023) | Sustainable Development | The objective of this systematic literature review is to provide a comprehensive overview of sustainable manufacturing (SM) adoption in the textile industry, identifying key drivers and barriers while categorizing existing research. | 170 | The methodology combined systematic literature review techniques with rigorous data analysis | The study reveals a complex interplay of drivers, such as regulatory pressures and consumer demand, and barriers like high costs and limited awareness, influencing the adoption of sustainable manufacturing. |
| 4 | The emergence of sustainable manufacturing practices | Despeisse et al. (2012) | Production planning and control | This study aims to conduct a comprehensive review of sustainability methods as documented in literature published between 2000 and 2010 | 83 | Analyses various sustainability activities, focusing on the factors that enable sustainability and employing lifecycle assessment methodologies. | The primary finding of this study is the necessity of creating a framework for evaluating sustainability and making recommendations for future research on the application of sustainable manufacturing. |
| 5 | Uptake of Sustainable Manufacturing Practices By Food Manufacturing Firms: A Systematic Review | Rajendran & Sharaai, (2020) | International Journal of Advanced Science and Technology | Examine and consolidate the current literature regarding the adoption of sustainable manufacturing practices The study seeks to | 31 | The researchers conducted a comprehensive search using databases such as Google Scholar, Science Direct, and | Key findings indicated that economic motivation was the primary driver for adoption, followed by national legal obligations and |

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| | | | | identify and analyse the independent factors that affect the adoption of sustainable standards or tools in both developing and developed countries. | | Scopus, employing specific keywords related to food manufacturing , adoption, and sustainability practices in both developing and developed countries. | learning capacity, with a notable skew towards developed countries and larger firms compared to their developing country counterparts and small-and-medium enterprises |

Table 2: Detailed analysis of some existing review of literature on sustainable manufacturing

| Sl. No | Title | Authors | Publication | Objective | No. of papers Reviewed for the study | Methodology | Result |
|---|---|---|---|---|---|---|---|
| 6 | The concept of sustainable manufacturing and its definitions: A content-analysis based literature review | Moldavska & Welo, (2017) | Journal of Cleaner Production | Clarify the various definitions and interpretations of sustainable manufacturing found in existing research. | 189 | Analysing 189 articles published between 1990 and 2016, the authors aim to identify common themes, discrepancies, and the evolution of the concept of sustainable manufacturing | The study concluded that there is a significant lack of consensus on the definition of sustainable manufacturing |
| 7 | A systematic literature review to map literature focus of sustainable manufacturing | Malek & Desai, (2020) | Journal of Cleaner Production | To explore various insights from past literature to enhance the adoption of Sustainable Manufacturing | 124 | Comprehensive search was conducted using the SCOPUS database to identify relevant articles published between January 2001 | The study found that a significant portion of the literature on Sustainable Manufacturing lacks a systemic approach, with many articles |

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| | | | | | | and March 2019. | focusing on segmented rather than integrated sustainability assessments. |
| 8 | Review on multi-criteria decision analysis in sustainable manufacturing decision making | Jamwal et al., (2021). | International Journal of Sustainable Engineering | The objective of the study is to investigate the applications of multi-criteria decision-making (MCDM) in sustainable manufacturing (SM) and to identify the strengths and weaknesses of existing MCDM techniques. | 78 | Identified a need for more industry-specific research and highlighted the limited attention given to social aspects of sustainability, suggesting that future studies should address these gaps to enhance sustainable manufacturing practices. | Identified a need for more industry-specific research and highlighted the limited attention given to social aspects of sustainability, suggesting that future studies should address these gaps to enhance sustainable manufacturing practices. |

Table 2: Detailed analysis of some existing review of literature on sustainable manufacturing

| Sl. No | Title | Authors | Publication | Objective | No. of papers Reviewed for the study | Methodology | Result |
|---|---|---|---|---|---|---|---|
| 9 | Review of lean-green manufacturing practices in SMEs for sustainable framework | Sumant & Negi, (2018) | International Journal of Business Innovation and Research, | The objective of the study is to review and analyze the integration of lean and green manufacturing practices in small and medium enterprises (SMEs) to enhance sustainability | 16 | The methodology used in the study includes a comprehensive literature review to analyse existing research on lean and green manufacturing practices. Additionally, | The study found that integrating lean and green manufacturing practices significantly enhances operational efficiency and sustainability in SMEs, leading to |

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| | | | | and competitiveness. It aims to identify the challenges and opportunities faced by SMEs in adopting these practices, particularly in the context of the Indian manufacturing sector. | | the study discusses various multi-criteria decision-making (MCDM) techniques, such as Analytical Hierarchy Process (AHP) and PROMOTHEE, to evaluate and prioritize lean-green practices | improved economic performance and reduced environmental impact. |
| 10 | Sustainability indicators for manufacturing sectors: A literature survey and maturity analysis from the triple-bottom-line perspective | A Ahmad et al., (2018) | Journal of Manufacturing Technology Management | The objective of this study is to review sustainability indicators for the manufacturing industry, covering environmental, economic, and social dimensions. | 115 | The authors conducted a systematic review of existing studies, analysing various sustainability indicators from environmental, economic, and social perspectives. The identified indicators were critically evaluated, including their development and maturity level | The analysis revealed that solid waste management was the least addressed and least mature aspect of environmental sustainability in the manufacturing sector. Economic assessments were primarily limited to cost-based indicators. In terms of indicator usage, manufacturing activities in developed countries were generally more advanced than those in developing countries |

Table 2: Detailed analysis of some existing review of literature on sustainable manufacturing

| Sl. No | Title | Authors | Publication | Objective | No. of papers Reviewed for the study | Methodology | Result |
|---|---|---|---|---|---|---|---|
| 11 | Organizational enablers for sustainable manufacturing and industrial ecology | Hariyani & Mishra, (2022) | Cleaner Engineering and Technology | The purpose of this paper is to identify factors that enable sustainable manufacturing. Introduce sustainable manufacturing tools and practices to industry professionals and SMEs. Improve industrial ecology through sustainability gains. | 237 | Systematic literature review of the sustainable, green, lean, six sigma manufacturing enablers | According to the study, in order to successfully implement sustainable manufacturing, firms need to acquire a variety of enablers, including top management commitment, strategic planning, organizational culture, sustainable technology, measurement and reporting, and continuous improvement. |
| 12 | Green Manufacturing: An Evaluation of Environmentally Sustainable Manufacturing Practices and Their Impact on Competitive Outcomes | Rusinko, (2007) | IEEE Transactions on Engineering Management | This paper examines the relationships between specific environmentally sustainable manufacturing practices and specific competitive outcomes in the U.S. commercial carpet industry. | 26 | The paper used a two-phase approach in the first phase, the authors conducted a literature review to identify and categorise ESM practices. In the second phase the authors conducted a survey of manufacturing organizations in the United | The paper finds that environmentally sustainable manufacturing practices can lead to a number of positive competitive outcomes, including: Reduced manufacturing costs, Improved product quality, Enhanced corporate image |

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| | | | | | | States to collect data on implementation of ESM practices and competitive outcomes. | |

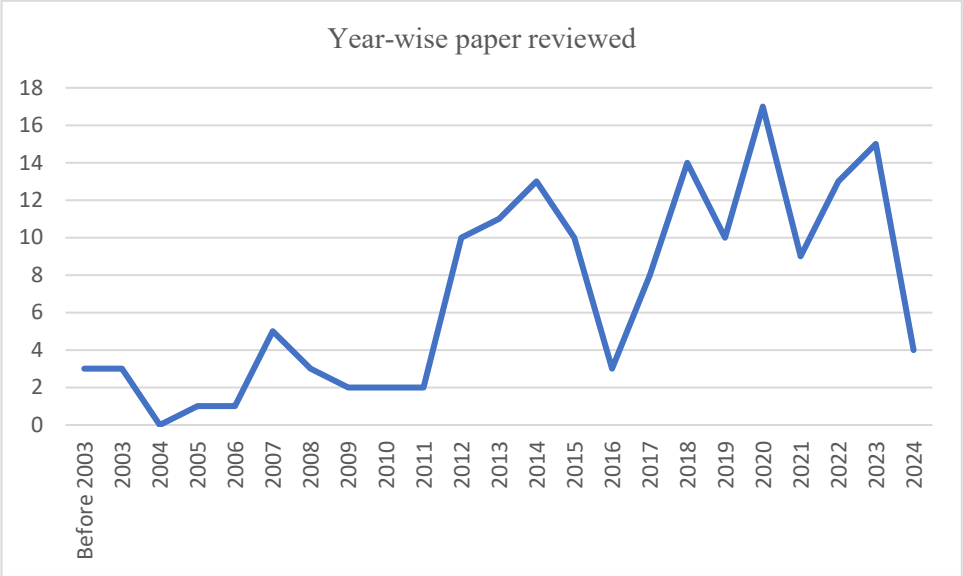



**Figure 3**: Year-wise paper reviewed

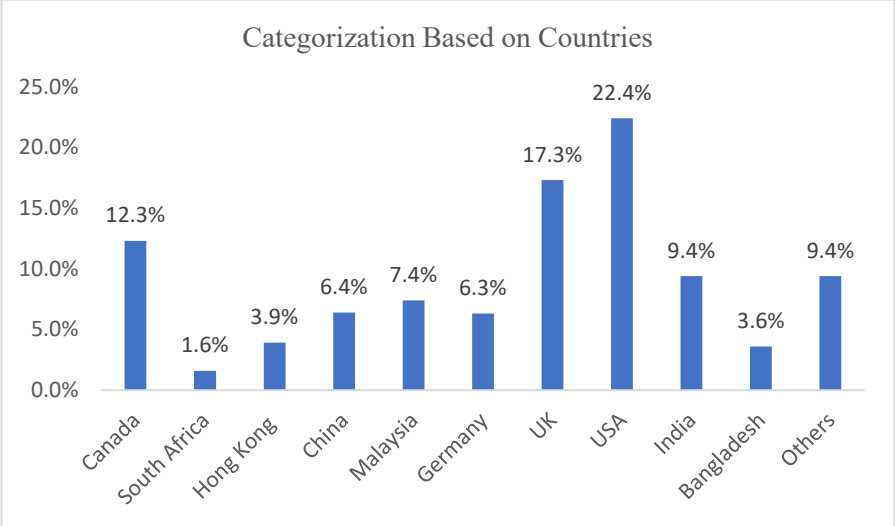



**Figure 4**: Categorization Based on Countries

**Table 3:** Sample Papers selected from Online Database

| Journal | No. of Papers |
|---|---|
| Journal of Cleaner Production | 20 |
| Sustainability | 8 |
| International Journal of Production Research | 6 |
| Environment Development and sustainability | 4 |
| International Journal of sustainable Engineering | 4 |
| Journal of Manufacturing Technology Management | 4 |
| Management of Environmental Quality An International Journal | 3 |
| Environmental Engineering and Management Journal | 2 |
| International Journal of Energy Economics and Policy | 2 |
| World Review of Entrepreneurship Management and Sustainable Development · | 2 |
| International Journal of Supply Chain Management | 2 |
| Environmental Science and Pollution Research | 2 |
| Environmentally Conscious Manufacturing | 1 |
| Clean Technologies and Environmental Policy | 1 |
| Environmentally Conscious Manufacturing | 1 |
| Global Business and Management Research: An International Journal | 1 |
| Green Manufacturing: Fundamentals and Applications | 1 |
| International Journal of Advanced Research in Engineering and Technology | 1 |
| International Journal of Advanced Manufacturing Technology | 1 |
| International Journal of Advanced Science and Technology | 1 |
| International Journal of Engineering and Advanced Technology | 1 |
| International Journal of Management Reviews | 1 |
| International Journal of Managing Value and Supply Chains | 1 |
| International Journal of Operations and Production Management | 1 |
| International Journal of Physical Distribution and Logistics Management | 1 |
| Journal of industrial and production Engineering | 1 |
| Production Engineering Archives | 1 |
| Advances in production engineering and Management | 1 |

A comprehensive analysis of prior literature in SM highlights the need for additional research to address unanswered questions. In today's world environmental sustainability is a critical component of business strategy for all industries (Bogue, 2014). Given the triple bottom line (economic, environmental, and social) focus of SM, further research is needed to fully understand the distinctive characteristics of this field (Garetti & Taisch, 2012). It is clear from Table 2 that there have been a growing number of review studies on sustainable manufacturing, however these studies have not addressed all aspects of SM. Malek & Desai, (2020) discovered that a significant portion of the research on Sustainable Manufacturing fails to adopt a holistic perspective. Many studies concentrate on isolated sustainability assessments, neglecting a more integrated approach. Jamwal et al., (2021) identified a need for more industry-specific research and highlighted the limited attention given to social aspects of sustainability, suggesting that future studies should address these gaps to enhance sustainable manufacturing practices. s It was found that prior research has often focused on particular domains within the subject matter. S. Ahmad et al., (2019) examined the prevalence of different sustainability

indicators in the manufacturing sector through a review of existing literature. According to (Hariyani & Mishra, 2022)in order to successfully implement sustainable manufacturing, firms need to acquire a variety of enablers, including top management commitment, strategic planning, organizational culture, sustainable technology, measurement and reporting, and continuous improvement.

Figure 3 reveals a clear trend in the research output on sustainable manufacturing practices. While the number of papers published before 2003 was limited, a significant increase is observed from 2007 onwards, reaching a peak in 2020. This surge suggests growing academic and industry interest in sustainable manufacturing, reflecting the increasing global emphasis on environmental responsibility and resource efficiency. However, a slight decline in publications is evident in recent years, potentially indicating a shift in research focus or challenges in accessing relevant data.

The data presented in Figure 4 shows a significant concentration of sustainable manufacturing research in developed countries. The United States and the United Kingdom together account for nearly 40% of the total studies reviewed, indicating a strong focus on sustainable manufacturing practices in these regions. While countries like China, India, and Malaysia have a growing presence in the research landscape, their contributions still lag behind those of Western nations. This suggests that there is room for further development and expansion of sustainable manufacturing research in emerging economies.

A comprehensive analysis of the selected sample papers from the online database represented in Table 3. The most frequently cited journals are the *Journal of Cleaner Production*, *Sustainability*, the *International Journal of Production Research* and Production Engineering Archives suggesting a focus on environmental impact reduction and production efficiency. Other prominent journals, such as the *International Journal of Sustainable Engineering* and the *Environment Development and Sustainability*, emphasize the social and economic dimensions of sustainability.

## 4. Sustainable Manufacturing: Exploring the Literature

This section provides a comprehensive summary of sustainable manufacturing practices, the barriers and enablers that affect their adoption, and the influence of laws and regulations.

### 4.1 Defining Sustainable manufacturing practices (SMP)

Sustainable manufacturing practices (SMP) are defined as those that improve productivity while also safeguarding the environment and fostering social and economic equity (Hinrichs & Welsh, 2003). This may be accomplished by taking social, economic, and environmental aspects (three pillars of sustainability) into account at every stage of the production process. According to Haapala et al., (2013) SMP are defined as comprehensive approaches that integrate environmental awareness, economic viability, and social responsibility throughout the manufacturing process, particularly emphasizing the importance of design and life cycle considerations. Different interpretations of the term can distort its meaning, possibly leading to the incorrect labelling of actions that do not actually contribute to sustainability (Moldavska & Welo, 2017). According to Malek & Desai, (2020) sustainable manufacturing emphasises on attaining financial benefits while ensuring environmental protection, thus promoting a comprehensive approach to manufacturing that boosts sustainability across multiple dimensions. Suitable technologies can facilitate a balance between human needs and environmental limitations, indicating that innovation is vital for implementing sustainable practices in manufacturing (Garetti & Taisch, 2012). Sustainable manufacturing techniques can help promote sustainable organizational development, which is necessary to preserve biodiversity. Hariyani et al., (2023) have identified different synonymous terms viz, sustainable production, clean manufacturing, cleaner production, environmentally conscious manufacturing, green manufacturing, environmentally responsible manufacturing, environment benign manufacturing, and sustainable manufacturing.

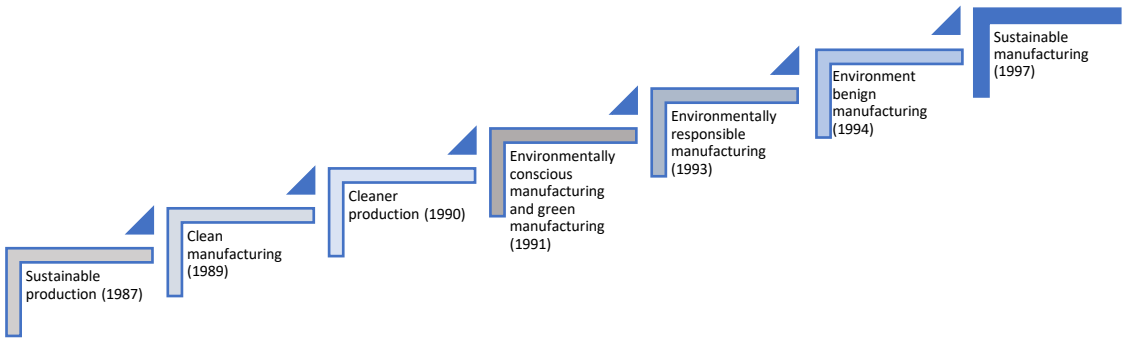



**Figure 5** Synonyms of Sustainable manufacturing (Jha et al., 2023)(Hariyani et al., 2023),

### 4.2 Sustainable Manufacturing Practices

There are several examples of sustainable manufacturing practices such as waste minimization (Mostaghimi & Behnamian, 2023), energy efficiency and management, waste reduction, resource use reduction, reuse, substitution (Despeisse et al., 2013), sustainable product development(van Weenen, 1995), waste management (Hamer, 2003), pollution prevention (Elleuch et al., 2018)**,** sustainable supply chain management (Acintya et al., 2022). Sustainable manufacturing practices and innovation can improve economic sustainability for manufacturers, so firms should focus on these areas to boost profits and create a more sustainable future (Hami et al., 2015). Adopting these production practices can be a valuable strategy for organizations that are looking to improve their competitive position and reduce costs, improve quality, and enhance their public image (Rusinko, 2007). This can also help firms improve to their performance, survive in the competitive environment (Vinodh & Joy, 2012) and help to progress their environmental performance, conserve resources, and ensure the safety of stakeholders (A. Ahmad et al., 2018). According to (Nordin, Ashari, & Rajemi, 2014) sustainable manufacturing practices are influenced by management factors, internal factors, and external factors. Management factors are those that relate to the leadership, decision-making, and organizational culture of a company. Internal factors encompass the resources, infrastructure, and processes within a company that directly influence its manufacturing operations and external factors including market conditions, regulatory requirements, and stakeholder expectations. Sustainability indicators can help manufacturing organizations identify areas for improvement, implement measures to reduce their environmental impact, and communicate their commitment to sustainability to their customers, suppliers, and other stakeholders. Joung et al., (2013) categorized the indicators of sustainable manufacturing into five dimensions, which are environmental protection, economic growth, social well-being, research & development, and performance management. These dimensions to evaluate the sustainability performance of a manufacturing sector. Small and medium-sized manufacturing enterprises (SMMEs) can improve their sustainability manufacturing practices by implementing life cycle costing, conducting life cycle assessments, conducting safety and health assessments, integrating sustainability into their strategic planning processes, investing in new technologies and practices, and collaborating with other businesses and organizations (Zhang et al., 2021). Human critical success factors (HCSF) are significant in driving the implementation of sustainable manufacturing practices. Strategic alignment, environmental consciousness, customer interaction management, leadership approach, and communication are key HCSF crucial for the successful implementation of sustainable manufacturing practices (Sharma, 2022). Achieving sustainable manufacturing necessitates comprehensive consideration of the entire product lifecycle, spanning from raw material acquisition to disposal. This demands the development of novel models, methodologies, and tools to assess and enhance the sustainability of products, processes, and systems (Jayal et al., 2010). (Millar & Russell, 2011) have found that adopting sustainable production practices can have an adverse effect on business performance in the short term. However, these practices can lead to long-term competitive advantages and better business performance. Therefore, companies should focus on sustainable strategies that improve resource efficiency and boost both sustainability and competitiveness and achieve cleaner production at a reduced cost. A detailed examination of commonly researched sustainable manufacturing practices is presented in the following section

### 4.2.1 Sustainable product development

The most important component of sustainable manufacturing is probably product design since it determines a product's environmental effect in the early phases of development. (Bogue, 2014). Sustainable products are those products that improve the quality of the environment and society (Gmelin & Seuring, 2014). The emphasis of sustainable product development should be on "sustainable design" (Kaebernick et al., 2003). Srivastava, (2007) emphasizes that design for the environment principles encompass disassembly, remanufacturing, recycling, and even pollution prevention at the design stage. This may necessitate adjustments to raw materials, production processes, or product specifications**.** The necessity of integrating environmental considerations into product development is well-established, with over a decade of discussion emphasizing the importance of assessing a product's lifecycle from design to disposal, including its social, economic, and environmental impacts (Van Weenen, 1995). Every stage of a sustainable product, from manufacturing to disposal, is designed to minimize its environmental impact and maximize resource efficiency (Kaebernick et al., 2003)**.** To ensure a product is sustainable, it is crucial that the environmental, social, and economic impacts (TBL criteria) are measurable. Simply evaluating a product's performance is not enough to determine if it is sustainable (Gmelin & Seuring, 2014). Sustainable product development not only reduces environmental impact but also offers significant economic and operational benefits. By mitigating risks like product recalls and supply chain disruptions, while driving innovation and cost savings through product redesign and improved manufacturing processes, businesses can achieve long-term sustainability and competitiveness (Bogue, 2014).

### 4.2.2 Waste Management

Waste management comprises a wide range of operations carried out at different degrees of complexity, such as reduction, recycling, segregation, modification, treatment, and disposal (Hamer, 2003). Since every activity generates some waste, responsible environmental practices demand waste management as a baseline requirement (Agan et al., 2013). Waste reduction prioritizes preventing waste generation in the first place, unlike waste management which focuses on handling existing waste (Gupta et al., 2015). Qian et al., (2011) highlight the severe consequences of waste dumping practices, including groundwater contamination, toxin leakage, air pollution, and harm to plant and animal life. Many obstacles must be overcome in waste management, such as incomplete data, the qualitative character of recycling, energy recovery from garbage, achieving a balance between recycling goals and consumer safety concerns about recycled materials, and reducing the production of waste (Mostaghimi & Behnamian, 2023). The waste hierarchy (waste prevention, waste recovery, waste disposal), which prioritizes reduce, reuse, and recycle, serves as the basis for the majority of waste minimization techniques (Schiopu et al., 2018). In order to improve waste management in countries that are developing, strong and uniform regulations are essential. This should facilitate effective waste management procedures easier (Ilankoon et al., 2018). Boonmee et al. (2023) model describes post-disaster waste management as a multi-step process. The amount and types of waste generated vary depending on the disaster's severity. Waste is initially separated at the source before being collected and transported. Further sorting at designated locations categorizes waste into recyclables, compostables, and hazardous materials. Finally, the sorted waste is sent to appropriate facilities for treatment and disposal, such as recycling centers or landfills. The model prioritizes assessing the costs and environmental effects of each disposal method. Sadeghi Ahangar et al., (2021) presents a sustainable design for a municipal solid waste management system by creating an integrated closed-loop supply chain network, aiming to optimize waste collection, transportation, processing, and recycling while minimizing waste disposal and maximizing resource recovery.

### 4.2.3 Pollution prevention

Pollution is a consequence of waste generation, preventing pollution is fundamental to achieving sustainability (Elleuch et al., 2018). Pollution prevention cuts pollution at the root by reducing or eliminating waste before it even exists. Pollution prevention involves designing or modifying processes to minimize waste generation. (Schiopu et al., 2018). The goal of pollution prevention is to minimize or entirely eliminate the production of pollutants by making the best use of energy, raw materials, and natural resources while acknowledging the persistent and serious problem of resource depletion (Petraru & Gavrilescu, 2010).

### 4.2.4 Sustainable supply chain management

Sustainable supply chain management (SSCM) is well-defined by Seuring & Müller (2008) as "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements". SSCM emerges from microeconomic perspective by aligning the three pillars of sustainability with fundamental business functions. These core functions include procurement, logistics, knowledge management, marketing, and operations (Morali & Searcy, 2013). Carter & Rogers, (2008), proposed a framework where companies can gain a competitive edge by integrating long-term sustainability goals throughout their entire supply chain. Sustainable supply chain management can enhance through digital technologies**.** By incorporating environmental and social considerations into their operations, businesses can optimize their supply chains, minimise waste, and improve effectiveness (Kumar et al., 2023). The manufacturer's behavioral preferences have a significant impact on pricing, order decisions, and the profitability of both the manufacturer and the retailer within the supply chain management (Jian & Wang, 2018)

### 4.2.5 Energy Efficiency and Management

Energy management strategies that improve the efficiency of manufacturing processes. This involves investigating optimal methods for resource utilization and incorporating sustainability principles into manufacturing design and operations (Peter & Mbohwa, 2019). The future of manufacturing depends on a comprehensive, lifetime strategy to energy efficiency development. It must be integrated at every stage, from the initial phases of product development and production planning to engineering, manufacturing, and post-production services, in order to optimize the benefits. For manufacturing sector to remain sustainable, there must be a constant push to increase energy efficiency (Cai et al., 2022). The most well-known sustainable manufacturing methods covered in the literature will be presented in the Table 4.

**Table 4:** Sustainable manufacturing practices from literature

| Practices | Source |
|---|---|
| Implementation of closed-loop manufacturing processes, Stakeholder engagement, Adopting advanced technologies, Pollution prevention, product stewardship | (Ali et al., 2021), (Zhang et al., 2021), (S. Ahmad et al., 2023), (Garetti & Taisch, 2012) |
| Using renewable energy sources, reducing water consumption, reducing waste production, using recycled materials, improving energy efficiency, promoting health and safety of employee | (Madan Shankar et al., 2017) |
| Environmental demands from those involved, managerial support, and staff participation, Top management commitment, staff participation, efficient communication, sufficient resources, and proper technology. | (Aboelmaged, 2018), (Vinodh & Joy, 2012) |
| Sustainable buying, natural resource conservation, Product design, environmental preservation and management, circular economy, green supply chain management, and green certification | (Saman, 2012) |
| Considerations include customers, legislation, social responsibility, anticipated benefits, waste disposal and treatment, waste reduction, recycling, design, and environmental management systems | (Agan et al., 2013) |
| Waste minimization, energy efficiency, water conservation, material efficiency, sustainable product design, and life cycle assessment | (Abdul-Rashid, Sakundarini, Ariffin, et al., 2017) |
| Sustainable manufacturing, ecological efficiency, relationships with the community, closed-loop production, relations between employees, vendor relations, and relationships with clients | (Hami et al., 2019) |
| Cleaner manufacturing, lean methods, green supply chains, eco-design, product recovery, and process design | (Gupta et al., 2015) |

**Figure 6** Bibliometric Analysis of keywords

Bibliometric analysis is a widely used research methodology that allows scholars to quantitatively assess the historical development and potential future of scientific research (Bhatt et al., 2020). Figure 4 illustrates the intricate relationships between various concepts in the domain of sustainable production practices. At the core lies "sustainable manufacturing," encompassing economic, environmental, and social dimensions. Key themes also include "sustainable development," "manufacturing practices," "supply chain management," and "technology adoption." The "triple bottom line" emerges as a pivotal framework for evaluating sustainability performance, while terms like "pollution prevention," "waste management," and "resource-based view" emphasize the environmental aspect.

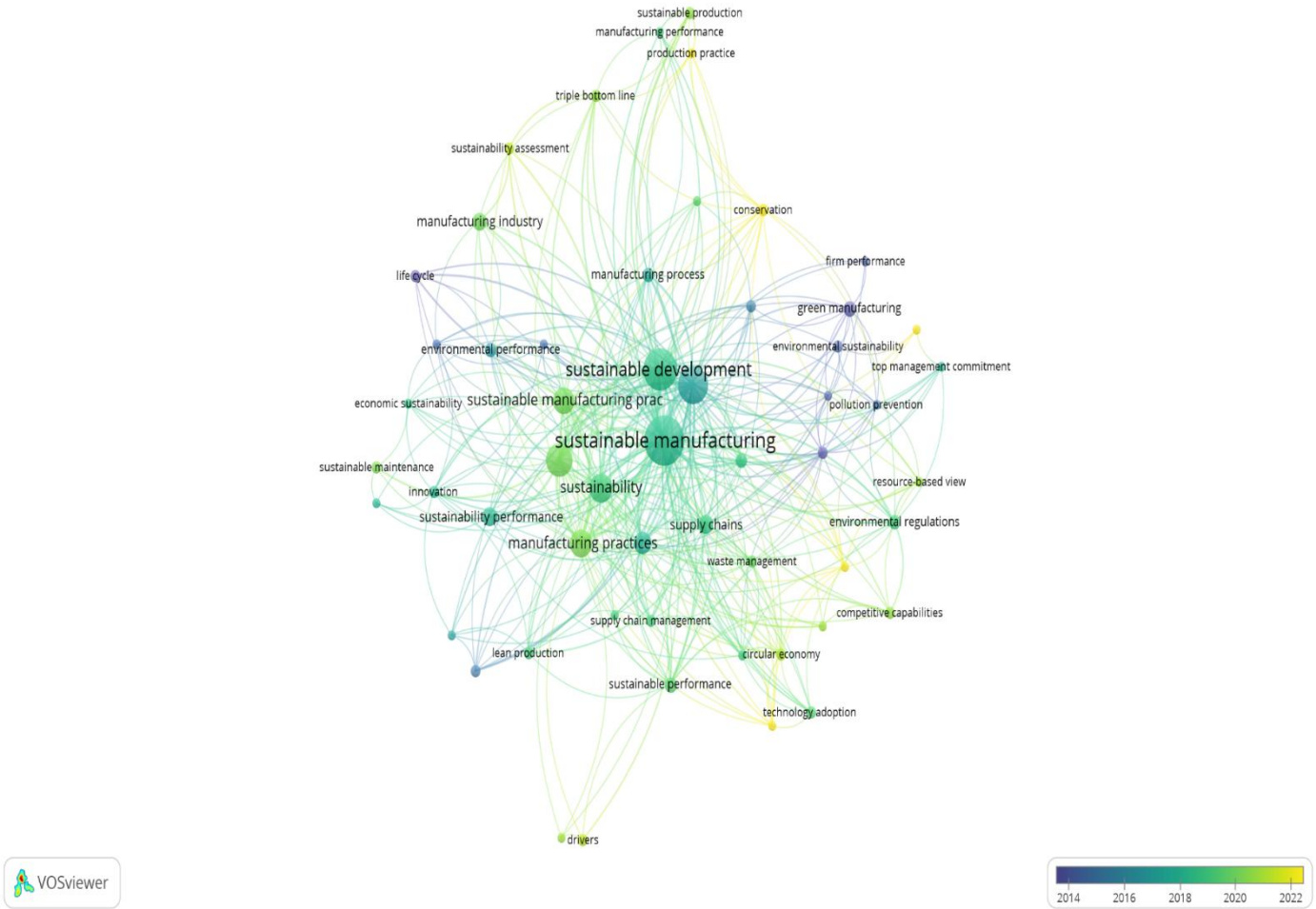
### 4.3 Drivers and Barriers to Sustainable Manufacturing Practices

The development and use of sustainable manufacturing practices are impacted by the drivers and barriers. Drivers are typically linked to fundamental survival, whereas motivations are the impulses that lead to objectives or advantages (Hariyani et al., 2023). Several studies have identified key drivers of sustainable manufacturing practices. Md. Abdul Moktadir, Towfique Rahman, Md. Hafizur Rahman, (2018) found that understanding the circular economy was a primary motivator for large-scale leather companies in Bangladesh. Aboelmaged, (2018) highlighted the positive impact of stakeholder pressure, management support, and employee engagement on sustainable manufacturing practices in Egyptian SMEs. (Mittal & Sangwan, 2014) highlighted incentives, public pressure, and legislation as the primary drivers of green manufacturing activities in the context of rising and developing economies. The adoption of sustainable

manufacturing in various industries results in reduced expenses, increased profit margins, improved innovation, and a reduction in the adverse environmental effects of manufacturing processes (Jamwal et al., 2021). Lean and green practices offer synergistic benefits for SME sustainability, enhancing economic performance while minimizing environmental impacts. However, resource constraints and awareness gaps hinder widespread adoption. This study proposed by Sumant & Negi, (2018)a framework to address these challenges and promote sustainable manufacturing in SMEs.

Many firms are voluntarily adopting sustainable manufacturing systems to gain long-term competitive advantages. However, some organizations have not implemented these systems due to various barriers (Bhanot et al., 2015, Hariyani & Mishra, 2022, Malek & Desai, 2019) or because of lack of different motivators or drivers (Aboelmaged, 2018, Md. Abdul Moktadir et al., 2018)

A comprehensive understanding of the fundamentals, metrics, forces, challenges, and indicators for sustainable manufacturing is required for the successful implementation of sustainable manufacturing practices (Madan Shankar et al., 2017). Among these factors, enablers are crucial in encouraging companies to successfully use sustainable manufacturing techniques. Industry professionals may more effectively exploit these enablers throughout the adoption process by recognizing and understanding their relative relevance. Implementing sustainable manufacturing strategies requires lowering the barriers and motivating the drivers (Pathak & Singh, 2019). Manufacturing organizations that would like to promote sustainability must prioritize important indicators which guide them in the right direction in order to get sustainable manufacturing outcomes (Bhanot et al., 2020). Achieving sustainable manufacturing requires a two-pronged approach: strong leadership commitment, employee involvement, clear communication, sufficient resources, and suitable technology alongside practices like waste minimization, energy efficiency, and life cycle assessment




(Abdul-Rashid, Sakundarini, Ariffin, et al., 2017). Environmental pressures from stakeholders, management support,

and employee engagement positively impact sustainable manufacturing, whereas factors like technology infrastructure, technology competence, and environmental regulations show insignificant effects on sustainable practices in Egyptian SMEs (Aboelmaged, 2018). Sustainable manufacturing in India is mostly driven by societal pressure and public concerns, indicating that Indian manufacturers are becoming more responsive to stakeholder and customer demands for sustainability (Garg et al., 2014). Manufacturers have been encouraged to combine eco-friendly business practices and develop successful green marketing strategies due to several factors, including environmental legislation, market competition, and corporate reputation (Jamil et al., 2022).

Sustainable manufacturing practices are crucial for the sustainability of the manufacturing industry, but their implementation faces challenges such as lack of awareness and high cost of investment (Despeisse et al., 2012). The drivers and barriers of sustainable manufacturing are presented in Tables 4 and 5.

**Table 5:** Drivers of sustainable manufacturing

| **Drivers** | **Source** |
|---|---|
| Circular economy | Md. Abdul Moktadir et al., 2018 |
| Stakeholder pressure on the environment, management support, employee participation, government grants or financial aid, and local government | (Aboelmaged, 2018). |
| Incentives, public pressure, and legislation | (Hermundsdottir & Aspelund, 2022) |
| lean product innovation | (Thomas et al., 2012) |
| Customer loyalty, Image of corporate social responsibility | (Jayaraman et al., 2012) |
| Brand image, and brand value | (Mittal & Sangwan, 2014) |
| Legislative requirements, and product stewardship, Emerging market and consumer prospects | (Rusinko, 2007) |
| Organizational sustainable performance | (Dubey, Gunasekaran, & Chakrabarty, 2015) |
| Better risk management, and environmental stewardship | (Joung et al., 2013) |
| Power consumption, manufacturing cost | (Jayal et al., 2010) |
| Government regulations and incentives, market demand, cost savings, technology, and reputation | (Seth et al., 2018) |
| Government promotions and regulations | (Bhanot et al., 2017) |
| A comprehensive view of manufacturing systems, Suppliers' involvement, Creating a sustainable culture inside the organization, Company Image, and Rewards | (Garg et al., 2014) |
| Product life cycle (PLC), 6R (reuse, recover, recycle, redesign, reduce, and remanufacture). Housing and service infrastructure, government restrictions. Technological advancement and consumer preference | (Gupta et al., 2015) |
| Government incentives and regulations, Access to information and resources, Collaboration with other businesses and organizations, Availability of financing, Customer demand | (Alayón et al., 2022) |
| Employee training and awareness, Environmental impact assessment, Sustainable supply chain management, Sustainable product design, Waste reduction and recycling | (Bhanot et al., 2020) |

| | |
|---|---|
| Current and future legislation, incentives, stakeholder pressure, cost and benefits, competition, customer demand, supply chain pressure, top management commitment, technological advancements, availability of organizational resources, and organizational image for sustainable manufacturing system | (Hariyani et al., 2023) |

**Table 6:** Barriers to sustainable manufacturing

| **Barriers** | **Source** |
|---|---|
| Lack of awareness and understanding of sustainable manufacturing (SM), Lack of government support and incentives for SM, High initial costs of SM implementation, Lack of skilled workforce for SM, Resistance to change from traditional manufacturing practices, Absence of top management commitment to SM | (Pathak & Singh, 2019) |
| Lack of knowledge and expertise | (Mittal & Sangwan, 2014) |
| Lack of government support | (Bhanot et al., 2015) |
| Customer resistance to higher prices | (Hariyani et al., 2023) |
| Absence of top management commitment | (Abdul-Rashid, Sakundarini, Ariffin, et al., 2017) |
| Management commitment | (Zhu & Sarkis, 2007) |
| Lack of collaboration | (Luo et al., 2017) |
| Lack of awareness, High upfront costs, Lack of expertise, cooperation from suppliers, awareness and resources | (Chourasiya et al., 2023) (Despeisse et al., 2012) |
| Lack of awareness and understanding of sustainable manufacturing, Financial constraints, Lack of technical expertise, Time constraints, lack of customer demand | (Alayón et al., 2022) |

The significance of various enablers and barriers varies depending on the unique characteristics of each business and industry. The drivers and motives for sustainable practices can differ based on factors such as the size of the firm, the industry in which it operates, and the country's regulatory environment (Hariyani et al., 2023)

### 4.4 Government policies and regulations

Government environmental regulations mainly focus to harmonize environmental protection along with economic growth. To achieve this, governments need to develop environmental policies fit to their specific economic conditions, organizational capabilities, and available resources (Xing et al., 2020). Governments around the world are implementing more regulations to encourage manufactures to adopt sustainable manufacturing practices (SMPs). Such regulations often restrict manufacturing processes to ensure efficient resource use, minimize environmental impact, and ensure social responsibilities (Ali et al., 2021). Manufacturers are under considerable pressure from various sources, including government regulations, social expectations, internal organizational policies, and environmental laws. Adopting sustainable manufacturing practices can help them to comply with these demands and improve their competitive position in the market (Chourasiya et al., 2023). Madan Shankar et al., (2017) highlighted that the implementation of

environmental regulations has driven improvements in clean production and resource efficiency in manufacturing sectors. Conversely, Aboelmaged, (2018) argued that environmental regulations have no impact on sustainable manufacturing practices (SMPs). Small and medium-sized enterprises (SMEs) demonstrate a positive trend in adhering to environmental regulations (Triguero et al., 2013). Panwar et al., (2016) suggested that such regulations not only motivate firms to engage in corporate environmental reporting but also potentially lead to cost savings. Environmental regulations can serve as a catalyst for economic growth by driving sustainable innovation and agile green business strategies. By promoting resource efficiency, limiting material usage, and incentivizing innovative production methods, these regulations can optimize resource value (Xing et al., 2020). Manufacturing companies can ensure compliance with environmental regulations, meet the growing demand for sustainable goods and services, and encourage suppliers to follow sustainable practices by developing plans for green purchasing (Malek & Desai, 2022). Adopting sustainable manufacturing techniques in Malaysian manufacturing industries is motivated by a number of factors, including government legislation, consumer demand, competition, technical advancement, cost savings, and enhanced reputation (Roni et al., 2014). Sustainable manufacturing is driven by interrelated eco-innovations, government laws, and environmentally beneficial technologies. Governments influence business operations through the implementation of environmental regulations and incentives. To comply with these restrictions and obtain a competitive advantage, firms create eco-innovations in response. These components combine to create an environment that is environment friendly (Hermawan et al., 2023). Adhering to regulations and legal necessities motivate firms' to adopt sustainable manufacturing practices (Rajendran & Sharaai, 2020). Studies indicates that sustainable manufacturing practices, driven by regulations and innovations, have a favourable impact on economic growth, societal welfare, and the conservation of the environment (three pillars of sustainability).

## 5. Conclusion

This review of sustainable manufacturing practices highlights the urgent need to address the global challenges we are currently facing. The analysis reveals a complex relationship of factors influencing the adoption of sustainable manufacturing practices, including drivers, barriers, regulatory pressures and technological advancements. Sustainable manufacturing increasingly emphasizes the combination of economic, environmental, and social (Triple Bottom Line dimensions). This approach identifies that sustainability is not solely about environmental protection but also about ensuring social equity and economic capability. The study highlights how different theoretical backgrounds helps in understanding the adoption of sustainable manufacturing practices. The resource-based view emphasizes the importance of unique resources and capabilities in achieving competitive advantage, whereas institutional theory explores the effect of external pressures on organizational practices. Stakeholder theory underscores the importance of considering the interests of various stakeholders, and the theory of planned behaviour provides insights into individual intentions and behaviours related to sustainability. Governmental policies and regulations play a crucial role in driving and shaping sustainable manufacturing practices. By setting standards, providing incentives, and imposing penalties, governments can significantly influence industry behavior and accelerate the transition to more sustainable practices. The review found that manufacturing industries face several challenges when trying to go green. It also highlights opportunities for innovation and competitive advantage.

## 6. Future Research Directions

- Sustainability Assessment: Developing and implementing frameworks that assess sustainability performance across all three pillars (economic, environmental, and social). This would help the manufacturing firms to quantify their progress and identify areas for improvement.

- Integration and Innovation: One of the key areas of focus is how to make current manufacturing operations more sustainable. This involves looking at new technologies, finding ways to improve existing processes, and even considering changes to how these businesses are organized.

- Technological Advancements: Future research can investigate the connection between new technologies and inventions in sustainable manufacturing. This could involve development of new materials and energy-efficient production processes, and implementation of circular economy models.

- Stakeholder Engagement: Examining the impact of sustainable manufacturing practices on various stakeholders, including employees, customers, and communities. This will help to find the advantages and challenges connected with the sustainability initiatives and stakeholder engagement.

Focusing on these areas in future studies will promote a more sustainable and environment friendly manufacturing sector. This will help reduce the environmental and social footprint of manufacturing, and enhance the economic benefits and also strengthening the competitive advantages of the manufacturing industries.

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