

Article

Integration of Lean Green and Sustainability in Manufacturing: A Review on Current State and Future Perspectives

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Abstract: The literature presents a review of the current application of lean and green practices and highlights the context, barriers, drivers, tools, and critical success factors and tools for the integration of lean and green practices within the Sub-Saharan African (SSA) manufacturing industry. In addition, the current state, gaps in the existing literature, and future perspectives on the current challenges of the industry have been suggested for the integration of both paradigm and sustainability of the industry. Integration of lean-green provides means to addressing issues faced by manufacturing industries for improved competitiveness. This study demonstrates that the application of lean and green practice is critical to be identified and applied within the region through the analysis of research papers published in both operational and sustainability journals. The findings of this review indicate that the synergy of lean and green practices is an effective initiative for resolving the operational and sustainability challenges of the manufacturing industry within SSA. To achieve operational excellence and mitigate environmental concerns, industries must implement the right tools and consider the critical success factors. By applying appropriate tools and models, the SSA region can address the current challenges and achieve a reduction in cost significantly.

Keywords: lean; green; sustainability; value stream mapping; manufacturing industry



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1. Introduction

The topic of lean and green manufacturing is a leading subject in both academia and industry. The concept of lean manufacturing focuses on value creation and its implementation approach is geared towards eliminating non-value-added activities from manufacturing processes with the overall aim to improve quality and productivity, hence delivering customer satisfaction. Comparatively, the concept of green manufacturing focuses on reducing environmental impacts from industrial activities that lead to sustainable outcomes; including increased profits and market share in the industries [1]. These sustainable outcomes address the concern for environmental issues by promoting greener products and cleaner operational activities within industries [2]. Additionally, it serves as a competitive advantage [3]. The challenge for manufacturing industries to attain operational excellence while achieving sustainable outcomes is increasingly becoming complex [4], more so in developing economies. In a case where an industry encounters incomplete utilization of materials, which often leads to the occurrence of defects and accumulation of waste, the existing technique for resolving this is the implementation of lean practice [5]. These practices eliminate inefficiency by reducing the non-value-added activities and engage tools such as poka-yoke (error-proofing methods) [6]. Hence, contributing towards achieving sustainable manufacturing and reducing waste or defects from the environment is considered by the application of lean practices.

Conceptually, the lean and green paradigms are different. However, environmental issues are resolved without compromising the productivity and competitiveness of an industry [7]. Although, the study of Carvalho et al. points out that the outcomes of both paradigms ‘lean’ and ‘green’ show a possible synergy between the two is more

likely [8]. Works of the literature suggest there is little understanding of how industries could implement both paradigms, especially in developing countries in Sub-Saharan Africa (SSA) [9]. The automotive industry contributed to the establishment of the lean philosophy and has remained at the forefront of integrating different paradigms for innovations in both products and supply chain activities. The application of this synergy exploits the advantages of both paradigms and reduces the effects of their weaknesses.

In SSA, the automotive industry now consists of all tiers of suppliers, from OEMs to tier two and tier three suppliers [10]. Hence, making the region a major player in the global industry. Moreover, to reduce the SSA automotive trade deficit and for the region to contribute its quota in achieving both efficient and greener manufacturing, an application of both paradigms must be considered. Countries such as Kenya and Nigeria are developing their own local automotive industry but with a lot of limitations that could potentially affect their manufacturing output [11]. These limitations include low-capacity utilization, very high cost of operations, and little or no technological transfer arrangements that result in high importation of materials extending lead time [11].

Similarly, for green manufacturing in the industry, the aim is to reduce pollution, and this begins with design and then to other industrial processes. There are various frameworks suggested for this review; however, from the various literature databases, there are limited resources on the application of both paradigms in the manufacturing industries within SSA. Attempts to integrate and apply lean and green practices within Western-dominated industries exist, there is a need to explore this integration and application in developing economies that contribute to global development and environmental concerns. For this reason, this paper attempts to explain the need for lean-green manufacturing in the value stream of the manufacturing industry in SSA.

1.1. Lean in Automotive Industry: Opportunities and Key Aspects

The automotive industry pioneered the lean paradigm through the Toyota Production System (TPS) by Taiichiro Ohno and Shigeo Shingo [12]. TPS is a system whose totality is greater than the sum of its constituent parts, and Toyota's accomplishment is not in making and using tools but in making all its processes a series of grouped, ongoing experiments irrespective of work demands [12,13]. In addition, TPS was made to implement a waste reduction policy as a strategic objective due to insufficient financial, human, and material resources resulting in an opportunity for growth from an economic challenge [14]. Furthermore, the term lean manufacturing was introduced during the Massachusetts Institute of Technology Motor Vehicle Programme where the aim of the research project was to link the performance gap between Japanese and Western automotive industries [15].

Lean manufacturing focuses on continuous improvement initiatives and cost reduction by eliminating non-value-adding activities [16,17]. Hence, lean manufacturing involves a systematic removal of waste and develops techniques to achieve this, but they vary in the prescribed approach to developing these techniques [18,19]. Ref. [18] suggested the use of value stream mapping, though objective but a specific method while [19] suggest a broader objective method. Ref. [20] also stated that the objective of lean manufacturing is to be receptive to customer demand by minimizing waste and producing products and services at the lowest cost and on time. The emphasis on customer demand differentiates it.

Various developing techniques and tools identified from works of literature range from value stream mapping, total productive maintenance, single minute exchange dies, Kanban, Kaizen, just-in-time (JIT), and poka-yoke. Presently a performance gap does exist in the SSA automotive industry, and it is pertinent to address this gap by reviewing the adaption of lean and its integration with the green paradigm through green value stream mapping.

1.2. Green in Automotive Industry: Opportunities and Key Aspects

Green manufacturing was established to reduce pollution, all forms of waste, and irrational consumption of natural resources, hence optimising its usage. In the design of green

manufacturing development, the following factors are considered: life cycle assessment, green design, and recycling of materials [21]. In practice, green manufacturing enhances the environmental performance (both product and process) and outlook of companies.

The automotive sector has relied more heavily on burning fossil fuel than any other sector, contributing about 37% of carbon emissions from consumers. According to the International Energy Agency, the automotive industry has been the highest contributor to carbon emissions on account of increased demand in many developing nations and economies. Hence, the goal of achieving net zero by 2050 has been agreed upon by many developed countries of the world, in a bid to ensure energy supply is constant and economic growth is without disruption [22]. In achieving net zero emissions, funding is required in the transition and the market for cleaner energy is readily available from supply chain connectors, procurement, and manufacturing companies.

Globally, road transportation contributes 15% of carbon emissions; with the implementation of net zero emissions by industries and countries, a decline from its current level is expected by the year 2050. The United Kingdom among other countries has renewed its policy to face off the use of internally combustible engines by the year 2035. Canada, the European Union, and China have similar policies in place in promoting net zero emissions. Several green operational activities, functions, objectives, and benefits ranging from green building, eco-design, or design for environment (DFE), green supply chain, greener manufacturing, reverse logistics, and innovations are suggested by works of literature to enhance the net zero emission objectives [23].

Many of the developing nations are yet to affirm their pledges of achieving net zero. Hence, global internal combustible engine car sales will continue to increase in these countries. In Sub-Sahara Africa, for example, Nigeria as a country depends greatly on burning fossil fuel in its generation of electricity and its current demand is greater than its current supply, hence facing an energy crisis. The manufacturing association of Nigeria has stated that more is spent on the maintenance of power generators in the running of industries, leading to an increase in energy costs [24]. Moreover, there are increased complexities involved with the design, production, usage, and end-of-life treatment of automobiles in the region which are of grave concern. Presently such renewed pledges do not exist within SSA automotive industry, and it is pertinent to address this gap by reviewing the adaption of green tools and their application through green value stream mapping.

This study demonstrates that the connection and application of lean and green practice are critical to be identified, highlighting the barriers, drivers, barriers, critical success factors, benefits, tools, techniques, and methods to be adopted in the application of both paradigms in the SSA automotive industry. The remaining sections in this review paper are as follows: Section 2 elaborates on the research methodology adopted for the review; Section 3 underscores a systematic review of lean and green practice; Section 4 reports the distribution and characterisation of the short-listed journal articles; Section 5 highlights the gaps and considerations for future research; and Section 6 concludes the study, with future perspectives as well as revealing the limitations of the study.

2. Methods

The aim of this research study is to demonstrate that the connection between lean and green is critical to be identified in order to maintain productivity and sustainability within manufacturing industries in Sub-Saharan Africa. The automotive industry amongst other industries emphasizes this critically, so it is pertinent to ascertain possible gaps, issues, and opportunities in essential journals. The vital step to seek areas that require detailed research study is through a literature review while highlighting that a literature review is an attempt to comprehend evolving research areas. Furthermore, theory development and conceptual frameworks of the research area are known through literature review. This review involves peer-review journals and books with varied impacts on the research area. The review was carried out considering the period between 1990–2022 because the debate, improvements, and integration of lean and green were immense within this time. Table 1

demonstrates an outline of the methods used. It was motivated by the method carried out by [25,26] in their literature review.

Table 1. Description of paper objective.

Article Section	Phases	Objectives	Method	Tools
Section 1	Introduction	Brief introduction into the research aims and objectives		
Section 2	Methodology, database selections and evaluation	Method Applied and literature review	• Use of electronic data bases • Definitions and search periods • Definitions and search inclusion criteria • Areas of application	• ScienceDirect (Elsevier), Emerald, Springer, Taylor and Francis, IEEE, Google scholar. • 1990–2022 • Lean manufacturing, Green manufacturing and Sustainability. • Manufacturing and production industries; Automotive industry
Section 3	Literature Review			
Section 4	Analysis and Categorisation of articles	Analysis and categorisation of selected journal publications	• Distribution across time period- • Categorisation of journal publications	Descriptive analysis Microsoft Excel
Sections 5 and 6	Reporting of findings and conclusion	Performance measurement and future perspectives and limitations.		

The literature review was conducted by utilizing electronic library databases including ScienceDirect, Emerald and SpringerLink, Taylor and Francis, and IEEEExplore. Consequently, the search involved the use of keywords as shown within the period of 1990–2022 as presented in Table 2.

Table 2. Database and keywords.

Electronic Library Database	ScienceDirect, Emerald and SpringerLink, Taylor and Francis and IEEEExplore
Keywords	Lean, Lean management, Lean and Value Stream Mapping
	Green, Green management, Green and Value Stream Mapping, Green Value Stream Mapping and Sustainability
	Lean and Green, Green and Lean
	Value Stream Mapping
Area of Application	Manufacturing and Production industries

3. Literature Review

This literature review has been considered from the perspective of lean, green, the synergy of lean and green, and the application of lean and green manufacturing in the manufacturing industry respectively.

3.1. Lean Manufacturing

Lean addresses waste reduction and improving productivity from the inception of manufacturing processes. Studies show that the majority of the processes attached to manufacturing can lead to a higher percentage (as much as 95%) of non-value-added activities [27]. Therefore, many automotive industries have been able to implement this system of manufacturing to help improve both the efficiency and effectiveness of their daily operation leading to increased quality, the value of its products, improved customer service, and gaining more profit. Although several companies have failed to apply lean

manufacturing [28], lean manufacturing helps to optimise an operation process without compromising the quality of both product and service required by the customer.

A properly organised lean structure eliminates slack from a production system enabling workers with the needed skill to control their work environment and challenging them to remove barriers that impede workflow. Lean production empowers workers to creatively resolve challenges with the set of tools available. Additionally, the concept of lean operations enables companies to respond adequately to demands by producing and supplying at the right time, the right quality, and the right quantity of products at a less competitive price. To achieve these set goals, there must be reduced production costs, hence an improvement in the production process is necessary.

Lean practice provides a customer-centric application and highlights the practice of involving customers in separating value-added and non-value-added production activities, thereby helping to identify the source of advantage. A common challenge in the industry is identifying production waste (Muda) which requires a skill set from industrialists to identify. Eliminating production waste as shown in Table 3 below provides numerous benefits such as reduced lead time, improved performance, reduced risk and inventory, increased customer satisfaction, quality, and efficiency as well as improved financial performance, etc.

Table 3. Lean production wastes and description [29].

Waste Types	Description
Transportation	Unnecessary movements of parts and materials
Inventory	Stockpile of materials or information that increases lead time
Motion	Operational movement that often leads to fatigue or lowers performance of workers
Waiting time	An operational stop that causes machine or workers to halt
Overproduction	Producing in excess of the required demand
Over processing	Performing above the requirement as stipulated
Defects	This includes re-work, repair, re-inspection due to bad quality
Human resource	Inefficient use of workforce

Lean manufacturing is referred to as a combination of best practices that improves the overall efficiency, effectiveness, and productivity of an industry. There are several methods and tools available for the implementation of lean operations in various manufacturing organisations, as discussed within this paper, and in practice there are no limitations to the number of tools that can be combined in its application [30].

An extensive study has shown that implementing LM practices and philosophy can reduce production costs and improve quality [31]. However, few have translated these benefits into financial and economic indicators [32]. Due to the growing pressure from stakeholders, the need for continuous improvement is becoming more prevalent. This is why it is important that the pursuit of efficiency does not compromise the social and environmental conditions and despite the increasing interest in links between sustainability and LM, there are still limited studies on the link between these two factors [33,34].

According to various authors, LM can be used as a catalyst for companies to improve their environmental practices [35]. They see it as a stepping stone to more sustainable practices [36]. Despite the positive relationship between environmental outcomes and LM practices, authors and organisations often find it difficult to combine these two approaches due to the potential conflicts and trade-offs. Although LM practices can help improve the efficiency of a process, they are not enough to make it sustainable. Instead, they focus on incremental steps that can be used to make the process more sustainable, hence hindering a more radical innovative change to become truly sustainable. There has been limited research on social construct and LM practices, hence, the works of literature do not provide sufficient evidence to support the link between these two approaches.

According to some studies, LM practices can have a positive effect on the attitudes of workers due to their various benefits, such as autonomy, motivation, and work flexibility. However, others claim that the practice can be more repetitive and intense. Although, there is a consensus about the positive effects of LM practices on the health and safety of workers and its implementation in a more effective manner.

Lean Cases from Automotive Industries

The improvement of both operations and products are the priority of any auto manufacturer to remain competitive. Although lean researchers have raised concerns about the potential impact of environmental performance on an organisation's financial sustainability, in reality, improving it can help boost a company's profitability. For instance, implementing lean tools and techniques can help a company reduce its environmental impact.

One key technique to achieving this is the application of lean tools, i.e., value stream mapping. The current state of the manufacturing activities is revealed and mapped out, which details both non-value-added activities (NVA) and value-added activities (VA). The works of literature and industrial experience reveal that the majority of the operations carried out on the shopfloor are non-value-added activities. For optimum performance, corrective actions are implemented by eliminating NVA conducted by operatives within the value stream.

Ref. [37] alluded that the concept of VSM is a streamlined work process that uses lean manufacturing techniques and tools. It helps improve efficiency and reduce the risk of errors. According to [38], auto manufacturers can improve their performance in tough economic times by adopting a lean system. This method reduces costly errors and improves competitiveness. It becomes clear that LM assisted the Indian auto component business in a number of ways, including waste elimination, process stability improvement, improved inventory management, cost reduction, and production efficiency growth [39].

3.2. Green Manufacturing

Green manufacturing is one that centres on managing an organisation's environmental and social issues and uses techniques such as reverse supply chain management [35], life cycle assessment [40], and sustainable value stream mapping [41]. Green manufacturing deals with less pollution and reduction of waste after the life cycle of products. These can be achieved, for example, through recycling, reducing, reusing, and replacing parts. Several approaches have been considered to providing a sustainable environment such as control, prevention, and product stewardship [42], and Life Cycle Assessment (LCA) are classified as best for assessing the impact of a system on the environment [43].

To achieve sustainable outcomes, the traditional model of production and consumption where products are used and eventually disposed of (linear economy) must change. This conventional method has created sustainability crises in different forms such as environmental degradation and scarcity of resources. A shift from non-renewable materials to renewables to promote a circular economy is necessary for every production system to resolve environmental and economic challenges [44]. Creating a closed loop supports remanufacturing and recycling of components, as in the case of a steel recycling and manufacturing process.

A closed-loop steel recycling process is a system in which steel scrap is collected, processed, and recycled back into new steel products in an ongoing cycle, without the need for raw materials. This process has several key steps:

Raw material extraction and collection: Steel scrap is collected from a variety of sources, including manufacturing facilities, construction sites, and consumer recycling programs.

Processing and distribution: The collected steel scrap is sorted and processed to remove impurities and contaminants. This may include shredding, magnetic separation, and other methods.

The manufacturing stage includes:

Melting: The processed steel scrap is melted in a furnace, either in an electric arc furnace (EAF) or a basic oxygen furnace (BOF).

Refining: The molten steel is refined to remove impurities and control the chemical composition of the final product.

Casting: The refined steel is cast into various shapes and sizes using techniques such as continuous casting or ingot casting.

Rolling: The cast steel is rolled into sheets, bars, or other shapes using a rolling mill.

Fabrication: The rolled steel is fabricated into finished products such as automobiles, appliances, and buildings using processes such as stamping, forming, and welding.

End of life/Brown recycling: When the steel products reach the end of their useful life, they can be recycled back into the closed-loop process, starting with collection.

Hence, the closed-loop steel recycling process as shown in Figure 1 allows for the continual reuse of steel scrap, reducing the need for raw materials and minimizing waste.

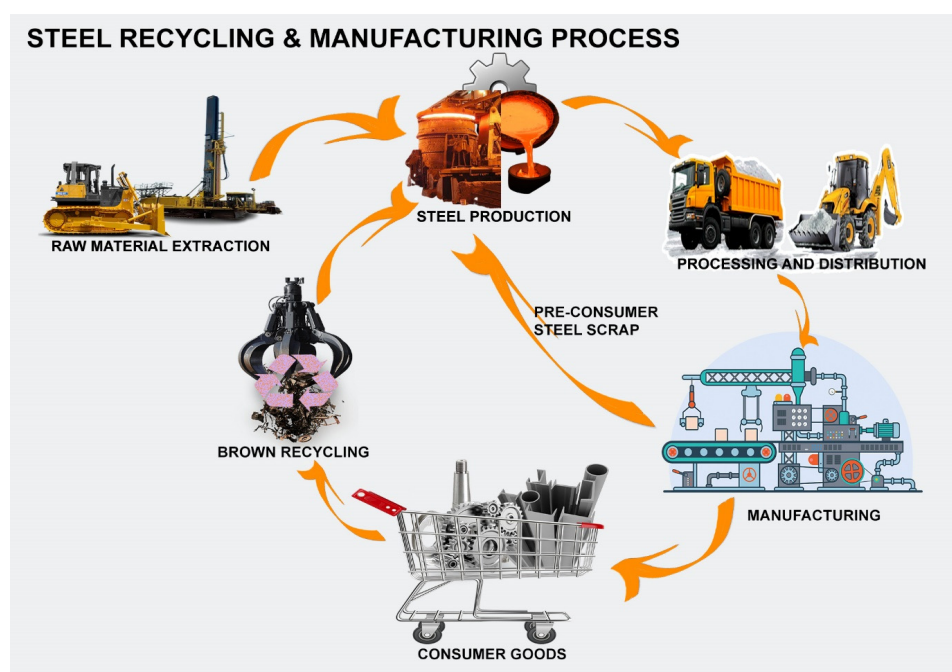


Figure 1. A steel recycling process (closed loop).

Sustainability affects several aspects of the industry and could practically be challenging to manage except industries adopt sustainable practices in their transformational process of production. In this regard, the circular economy has gained traction in both academics and industry. Employing environmentally friendly practices within production processes is practical which involves the use of low energy, reuse and recycling of materials, and the use of lightweight materials. However, the cost of engaging in such practice is high, and the knowledge and skill required are also scarce [45] which can pose a challenge to the adoption of green practice in many industries especially in developing economies of the world such as the SSA region. Though the works of literature support the adoption of a circular economy within many industries, clarity on how emerging technology actually supports green practices are yet to be explored [46,47].

Green waste can be categorised as follows in Table 4:

Table 4. List of green waste and its description.

Green Waste Types	Description
Energy	Over utilization of power from various machinery
Water	Excessive use of water
Material	Non-recyclable material or defective products would constitute as garbage contributing to the landfills causing pollution
Gas emission	Release of toxic gas into the atmosphere
Transportation	Unnecessary movement of materials or people from a location to another
Biodiversity	Disposal of items that contribute to garbage accumulation leading to environmental challenges
Garbage	Disposal of items that contribute to environmental challenges

Lean Cases from Automotive Industries

Toyota Group's latest environmental reports are categorised into four different factors based on their organisational perspective. These include the vision and structure, environmental aspects, social aspects, and economic aspects. Toyota's US dealer facility was built to meet the energy and environmental design standards of the LEED program. It uses less energy and is 35 percent less water-efficient than conventional structures. According to reports, these measures have led to lower costs and increased the dealer's direct benefits. Furthermore, Toyota is working on various initiatives to improve the company's eco-design. Some of these include developing new technologies that can help reduce engine emissions, as well as developing clean-energy vehicles.

Toyota has already started using hybrid engines. However, this is not the company's only strategy when it comes to developing new technologies to power its cars. The company is exploring other options such as hydrogen fuel cells and electrical batteries. Toyota is also exploring new materials that can be used in its production process that are both eco-friendly and sustainable. Some of these include natural fibre, recycled plastics, and eco-plastics. The company provides a convenient and easy way to recycle vehicles in response to European and Japanese legislation regarding the recycling of automobiles.

Toyota is also working on improving its supply chain by implementing more efficient methods of moving vehicles. The company uses trains to transport its products instead of trucks. In addition, it must follow strict guidelines and regulations when it comes to working with its suppliers. Toyota is also working on reducing its environmental impact by implementing various green initiatives. These include the purchase of renewable energy sources, training its employees on how to reduce their consumption, and recycling programs.

General Motors:

In addition to its Corporate Responsibility Report, which provides a comprehensive view of the company's environmental activities, GM also has a set of metrics [48] that measure its various facilities' energy use and greenhouse gas emissions. The company has also started implementing solar panels on the roofs of its facilities. This practice is part of its efforts to promote sustainable building practices. Furthermore, GM has also launched a training program for its employees on how to use the Design for the Environment concept. This program aims to help them reduce their emissions and improve the fuel economy of their cars.

The goal of the GM Supplier Relations initiative is to improve the environmental performance of the organisation's partners. This is accomplished through the development of sustainable design and energy efficiency. During a forum, the participants discussed various issues related to the environment. All General Motors' tier-one product suppliers must have an Environmental Management System (EMS) that is compliant with ISO 14001 [49]. This standard helps them manage their environmental activities in line with the company's

legal requirements. Apart from being able to comply with the standard, the implementation of this program also allows them to continuously improve their performance.

In terms of waste management, General Motors has set goals for reducing the amount of non-hazardous and hazardous waste that it produces at its facilities. This program is carried out through the implementation of various strategies and procedures. One of these is the reduction of coal-burning systems. To avoid water and air pollution, the company has also started using cleaner-burning natural gas.

Through partnerships, the company is also developing reverse logistics systems that will allow it to collect and reuse end-of-life vehicles. It should also increase the proportion of materials that are reused or recycled to 95 percent.

Volkswagen Group:

The report on Volkswagen's environmental initiatives is divided into five parts. It covers various aspects of the company's operations, such as strategy and management, activities, and facts and figures. It does not include any mention of the company's efforts in developing green building practices. In addition to focusing on the environment, Volkswagen Group also aims to explore the long-term potential of non-carbon fuels. According to the company's report, improving the efficiency of its vehicles will not be enough to reduce emissions, as economic growth in developing countries will increase the demand for transportation. This is why the company is continuously looking for ways to improve fuel economy.

Volkswagen Group's suppliers must meet the company's sustainability requirements, they also must participate in training programs. One of the company's supply chain initiatives is to reduce the environmental impact of its operations. The company's environmental protection efforts are focused on the protection of water, air, waste, and energy. These are managed through its internal Environmental Management System (EMS). Through the use of advanced recycling systems, Volkswagen has been able to reduce its waste management activities. Europe is where the majority of the company's recycling takes place.

Major car manufacturers around the world are adopting various environmental practices when it comes to the construction and operation of their facilities. For instance, many of them are using green building certification for both their manufacturing and non-manufacturing facilities, designing for decoupling and recycling is the most common approach. Various initiatives have also been carried out to improve the efficiency of their logistics system. The automotive industry has had a pattern of how to improve their environmental performance. A progression from existing manufacturing processes to include non-manufacturing facilities and then the final disposal of toxic materials [23].

Due to the complexity of the green manufacturing processes, it has become more important that companies adopt a systemic approach. This paper will identify the various factors that prevent Sub-Saharan African automakers from fully implementing the programmes that concern environmental management systems.

3.3. Integration of Lean and Green Manufacturing

There has been a significant effort by various researchers to integrate lean and green approaches [7,8,50]. The aim is driven by the synergic effects of both approaches in lean and green value chains. However, bringing these approaches together does not provide instant benefits. There must be an in-depth understanding of how compatible these approaches are in certain industrial sectors and how they both help to optimise the use of resources. Lean practices are more likely to lead to greener results [42]. However, there is still a lack of evidence supporting the Green Pull. This is why it is important to observe that they work together seamlessly.

The three principles that govern the integration of lean and green practices are waste reduction, process-centered focus, and high levels of involvement and participation [51]. Several key performance indicators were also identified that are related to the integration strategy. These include lead time reduction, service level improvement, and the relationship between the customer [35].

The adoption of lean practices can lead to better practices in the green manufacturing industry. This is because the overlapping operational and environmental practices can be leveraged. An organisation can become lean and green by implementing environmental practices. These practices can help it become more efficient and reduce its waste which also is related to the seven lean wastes.

The goal of synergy is to enhance the relationship between partners by influencing each other in a positive manner. This can be accomplished through the development of new practices and the establishment of a common framework. In addition to being able to drive forward green practices, lean also must be able to enhance its own practices leading to economic sustainability but to create value maximisation, the environment, and society should be inclusive [52]. The results of this study revealed that when companies adopt green practices, they are more likely to achieve better results than those that do not. Hence, to achieve the necessary sustainability goals, a combination of green and lean practices has been proposed. This will allow companies to enhance their strengths and improve their reputation while also reducing their weaknesses [53]. It should also be noted that the two paradigms can bring significant benefits if they are integrated into a single framework to include the triple-bottom-line approach and yields a sustainable outcome within any industry. Lean and green overlapping concepts can be integrated as shown in Figure 2.

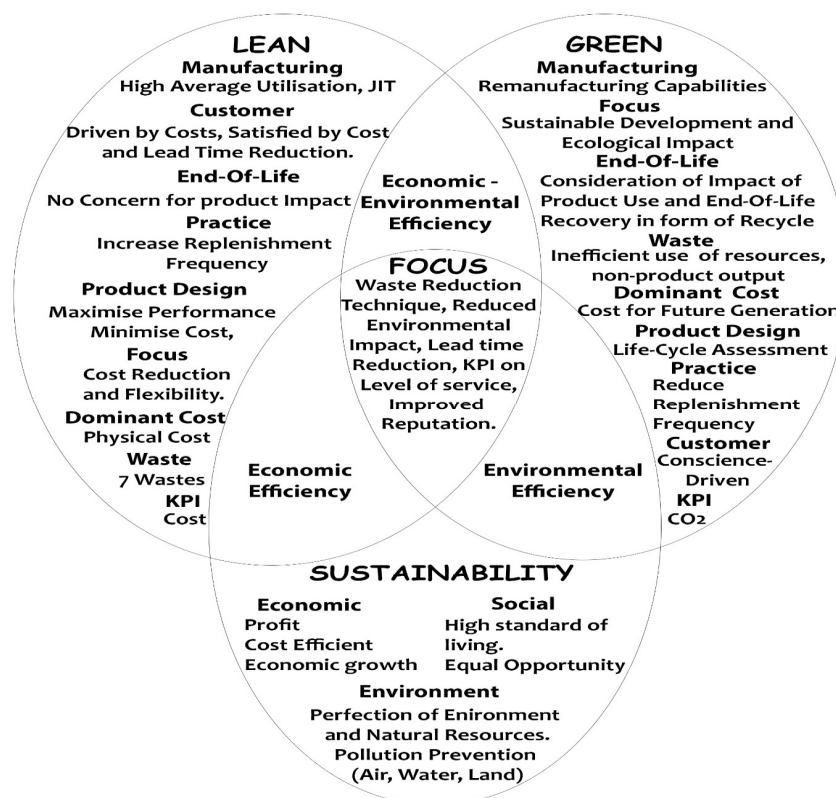


Figure 2. Lean and green integration.

Most companies are likely to adopt green practices due to the continuous commitment to lean production and this can be achieved through the development of new practices and the establishment of a common framework that supports optimal resource utilization (reducing waste) and energy efficiency. Despite the importance of the relationship between Lean and Green practices, there are still areas of conflict between the two paradigms. The only difference between Lean and Green is their different perspectives on the environment. While both lean and green practices recognise the importance of the environment, they may have to compromise in order to achieve an eco-friendlier product and service. For instance, while both practices are focused on improving the quality of their products and services, they may have to compromise in order to achieve a more sustainable environment.

Lean practices often prescribe an increase in the frequency of their replenishments through the use of a pull system and a JIT delivery method. On the other hand, green practices aim to reduce transport time and improve the efficiency of their operations. Table 5 shows the deliverables of lean and green waste generation.

Table 5. Lean and green waste integration modified after [54].

Lean Waste	Deliverables	Green Waste
Transportation	Excess motion	Energy and material
Inventory	Storage and scrap materials	Energy and material
Motion	Time loss	Garbage
Waiting time	Time loss	Energy
Overproduction	Production time loss, scrap and additional storage	Energy and material
Over processing	Production time loss	Energy
Defects	Scraps and production time loss	Material, energy and garbage

3.3.1. Green Value Stream Mapping (GVSM)

A valuable approach for sub-Saharan African regions to improve their productivity and green outlook is the adoption of green value stream mapping. The traditional application of VSM in the automotive industry, identifies non-value-added activities and value-added activities from an end-to-end process of manufacturing, allowing for a transformational process to occur. The visual view of both material and information flow identifies non-value-added activities which allow for the elimination of lean and green waste which have been identified in this paper. VSM improves the efficiency and effectiveness of equipment [55], harmonises information flow for the production process [56], improves lean operations, and reduces cycle time, reduces cycle time, production lead time, and work-in-process (WIP) in an auto-part industry [57]. In a pharmaceutical company, production lead time, cycle time, and WIP were reduced [58], and in a simulation-based study, the use of VSM increased demand with the addition of lean tools [59]. The contribution of the traditional VSM facilitates waste reduction but on the other hand, the inclusion of green practices in any value stream of an auto industry promotes integration and improves productivity and environmental performance.

Auto manufacturers such as BMW, Ford, General Motors, Honda, Mercedes Benz, etc. transitioning into electric vehicles to mitigate their contribution to environmental concerns while ensuring such feat does not impede productivity. In addition to improving the efficiency of their operations, green practices also aimed to reduce their energy consumption. This strategy is carried out through the recognition of the efforts of their staff members. Developing countries are tasked with reducing their carbon footprint [60].

3.3.2. Characteristics and Role of Lean and Green Application in Sub-Saharan Manufacturing

The manufacturing industry is a vital part of Sub-Saharan Africa's economy, but it faces various challenges. These include high energy costs, inadequate infrastructure, and lack of access to finance. Despite the growing interest in green and lean practices in SSA manufacturing, the implementation of these techniques has been slow. A report released by UNIDO stated that although many manufacturers are aware of the concept, they are still not fully prepared to adopt it [61]. In addition to this report, the lack of regulations and incentives is a major factor that prevents SSA manufacturers from adopting green manufacturing techniques, and the implementation of lean principles in Sub-Saharan Africa is limited.

In recent years, growing economies within the SSA region, are required to adapt the manufacturing process by applying green practices and contributing to reducing global environmental challenges. The use of green energy during manufacturing operations,

design and manufacture of green products are factors to consider in achieving sustainable goals. Unfortunately, there are several barriers that impede this inclusion but can be resolved through appropriate methods. Such barriers include and are not limited to:

1. Vehicles characteristics.
2. Capital Intensive.
3. Unreliable energy sources.
4. Importation of second-hand vehicles (ICEs).
5. Government policies.
6. Technological advancement.
7. Price.

The number of electric vehicles in Africa is limited in demand, though they offer numerous benefits such as emission reduction and sustainability, the barriers must be considered to reverse the current level of demand.

The biggest challenge is a lack of government support and regulations to encourage companies to adopt these practices. In the Sub-Saharan region, there may be limited political will to enforce environmental regulations and a lack of funding for relevant government agencies. Energy providers are struggling to provide enough for everyday consumption [62]. The political situation in Sub-Saharan Africa can present challenges for the implementation of lean and green practices, but there are also opportunities for progress.

Other critical aspects that require consideration in the application of lean and green practice include technological capabilities, cultural change, and improved political situation.

Technological capabilities that can be applied to support the implementation of these practices include the use of information technology (IT) to improve supply chain management and logistics. This can involve the use of software systems to track inventory, optimise routes for transportation, and monitor the performance of suppliers.

Another area is the use of automation and robotics to increase the efficiency of manufacturing processes. This can include the use of machines to perform tasks such as assembly, welding, and painting, which can reduce the need for human labour and improve the accuracy and consistency of the final product.

In addition, there are a number of technologies that can be used to improve energy efficiency and reduce the environmental impact of operations. This can include the use of renewable energy sources such as solar and wind power.

To foster a transition into green manufacturing, a coordination of lean and green strategies under the platform of green value stream mapping must be considered. Table 6 shows the characterization of the lean and green paradigm for achieving better outcomes for the SSA regions.

Table 6. Lean and green characterization [63].

Lean Paradigm		Green Paradigm
Focus	Waste elimination and continuous improvement	Reduction of environmental impact and priority to sustainability
Organisational Culture	Use of horizontal organisational structure	Reduce environmental impact through cross functional relations
Philosophy	Long term thinking	Long term thinking
Process	Improving processes	Develops a sustainable process
Performance Measurement	Resolves problems through feedback	Evaluation through green reporting
Management Involvement	Involves top management involvement and satisfaction	Involves management commitment
Employee involvement	Training and empowerment of employees	Employees should be educated

3.4. Implementation of Lean Green Manufacturing

3.4.1. Benefits of the Integration of Lean, Green Practice

Lean methods applied in today's global environment prevention activities and green management programmes can maximise their gains. In other words, lean tools can facilitate the competitiveness of pollution prevention approaches. Ref. [8] stated that market shares and profits of companies implementing both approaches increase. Table 7 highlights the benefits of lean and green practices.

Table 7. Benefits of lean and green practice.

Green Benefits	Lean Benefits
Circular economy encourages the recycling and reuse of materials.	Eliminate overproduction by consuming less material and reduce the cost associated with inventory.
The cost of energy while operating is reduced	Waiting time is improved upon to reduce production downtime
Emission and carbon footprints caused by unnecessary transportation are reduced	Unnecessary transportation increases the price associated with the product
Less energy usage is attained with the use of the appropriate number of materials.	Fewer materials are used by eliminating defects
Less energy is consumed while eliminating unnecessary motion, lifting and transferring of materials	Excessive movement and lifting of materials are completely reduced.

3.4.2. Drivers and Barriers to Integrating Lean and Green Practice

Manufacturing companies, mostly the automotive industry is geared towards sustainable development, promoting a circular economy which is an alternative strategy to attain both operational excellence and sustainable outcomes. However, there are drivers that promote this synergy and also barriers that have been identified by the several works of literature [45,64,65] that help managers in the successful implementation of both paradigms. As indicated in Table 8, the drivers highlighted are enablers of achieving sustainable practices within SSA automotive industry. Though the barriers are a challenge for the manufacturing industry, the pressure exerted by stakeholders and foreign investors facilitates the adoption of more sustainable production processes geared towards reducing their carbon footprint [66].

Table 8. Drivers to integration of lean and green practice.

No.	Drivers
D1	Pressure and expectation from the market
D2	Foreign investment and stakeholder expectation
D3	Long term economic benefits and performance
D4	Management and workers commitment
D5	Positive government policies and regulations
D6	Workers training
D7	Reduced waste and lower cost of manufacture
D8	Technological transfer and innovation
D9	Research and Development

Table 9 highlights the barriers posed to the implementation of lean and green practices within the SSA automotive industry have been identified in-depth mostly from academic literature and experiences from auto manufacturers and are classified under the following groupings. Existing academic literature under the databases of Google Scholar, Science

Direct, and Scopus was considered, and the keywords searched are ‘barriers to lean practice and implementation’, ‘barriers to green practice and implementation’, and ‘barrier to sustainability’.

Table 9. Barriers to integration of lean and green practice.

Lean Barriers	Green Barriers	External Barriers
Lack of expertise and technical training	Lack of environmental awareness	Poor governmental support
Poor commitment from top managers	Less interest in environmental issues and resistant to change	High price for consumer consumption
Low technological capabilities	Lack of information on product design and innovation	Poor infrastructure for return policies
Lack of continuous improvement culture	Insufficient training on sustainable process	Poor policies
Complex processes involving supply chain	Recovery and recycling of materials can be expensive and challenging	
Requires financial capital	Resource intensive at the initial stage of manufacturing	

3.4.3. Tools, Techniques, and Methods

There are several lean and green tools available in the literature to assist the manufacturing industry within the SSA region. The application of these tools in a constructive manner as projected in several case studies facilitated the reduction of production waste (refer to Table 3) and green waste (refer to Table 4). Hence, with the proper selection and application of the right tools as shown in Table 10, the current challenges of the industry can be resolved.

Table 10. Lean tools and description.

Lean Tools	Description	References
5s	The systems help to organising space and effectively manage production factors efficiently and safely	[67]
VSM	The visualisation of the entire process flow including material and information flow for the identification and elimination of non-value-added activities	[55,56]
SMED	Improvements tool to facilitate reduction of setup time and increase production flexibility and more frequent product mix changes	[68,69]
KANBAN	A pull system that employs the use of signal in every manufacturing process to improve and reduce bottle necks.	[70,71]
KAIZEN	A collective effort of the manufacturing companies to seek and implement all forms of continuous improvement within its processes	[72]
TPM	Optimises all maintenance strategy to achieve an efficient and productive equipment.	[73]
POKA YOKE	This is a mechanism that serves as an error prevention and helps operators avoid errors	[74]
JIT	A form of pull system that minimises waiting time, inventory, and defects. Products are manufactured on demand.	[31]
STANDARD WORK	A consistent method of performing tasks or processes. Usually involving the documentation and implementation of best-known ways of completing a task based on proven practices	[75]
CONTINUOUS FLOW	Initiates a smooth flow of work through a process. Eliminating interruptions, bottlenecks, and delays.	[76]

3.4.4. Lean Green Implementation Models

The lean-green implementation model is a process utilised by manufacturing firms to implement sustainable practices and principles into their operations. It aims to enhance the efficiency of its operations while reducing their environmental impact. One of the most effective ways to implement these models is through value stream mapping and continuous improvement. This process involves identifying various opportunities and procedures that will help eliminate waste.

Several works of literature have suggested a number of lean-green implementation models used by industries in developed countries and can be implemented by Sub-Saharan African industries. These models are highlighted in Table 11.

Table 11. Lean green implementation models.

Articles	LG Models	Findings/Benefits
[77]	Overall greenness performance for value stream mapping (OGP-VSM) model	The emission of the various processes as well as non-value-added activities were identified
[78]	Lean and Green House and maturity model	This process involves identifying and implementing strategies that will help eliminate both environmental and manufacturing waste
[79]	Lean and Green Model	The goal of this model is to reduce the average energy consumption, hazardous waste, and use of resources
[80]	The Sustainable Value Stream Mapping (Sus-VSM) model	In addition to identifying waste and creating value economically, this process also involved assessing the ergonomic conditions of the workers
[81]	VSM-DMAIC model (Define, Measure, Analyse, Improve and Control)	In a case study, areas where milk production waste occurred were identified and reduced
[72]	Gemba-Kaizen model	The case study was conducted for a multi-sectoral company and showed how the lean green implementation model can help improve the operational and environmental performance of the firms
[82]	Combined tools framework	The implementation of this model allowed the company to reduce its energy consumption. Additionally, through the use of various tools, such as Kanban, 5S, kaizen and visual management, the company was able to improve its material usage

The various implementation models shown in this study demonstrate how lean green practices can help companies improve their operations by saving cost, improving sustainability, satisfying customers, and reducing their environmental impact. Case studies were also conducted to show how lean green implementation models can be used in Sub-Saharan Africa. This suggests that manufacturing companies in this region can adopt, test, and validate these practices.

3.4.5. Critical Success Factors for Implementing Lean Green Manufacturing

In academia, works of literature have shown that lean can serve as a catalyst for achieving green objectives [35,42] and the benefits [8] stated in Table 7. Hence, the synergy of both paradigms within the manufacturing industry is achievable. To determine the performance measurement of both paradigms (lean and green) in the manufacturing industry, there are certain critical success factors to consider in the adoption of lean and green paradigms as highlighted by [83] in Table 12, similarly, a clear area of focus for both paradigms are shown in Figure 2.

Table 12. Critical success factor for lean green manufacturing.

Critical Success Factor for LGM	Authors
Management commitment	[84,85]
Employee involvement	[86]
Organisational culture	[87]
Skill acquisition for employees	[88]
Health and Safety	[89]
Government Legislation	[90]
Supply chain issues	[91]
Technological aspects	[92]

4. Descriptive Analysis

4.1. Journal Publications across Time Periods

Figure 3 illustrates the annual distribution of publications ranging from 1990 to 2022 from which 118 research articles were reviewed. This highlights the pattern of research articles published over the past decade of review.

4.2. Journal-Article Publications Categorisation

The classification of several articles according to their publications is demonstrated in Figure 3 from which the Journal of Cleaner Production had significant contributions in the field of lean and green practice. Following closely are Production Planning and Control, The Management of Operations, and Journal of Manufacturing Technology/Clean Technologies and Environmental Policy. Consequently, it has been determined that research on lean and green integration is published in a range of specialised journals.

4.3. Article Categorization for Keywords

Figure 4 indicates the distribution of articles for lean and green independently and an integrated approach of lean and green. Furthermore, it has been observed that the majority of the research conducted focuses on Lean and Green comparison.

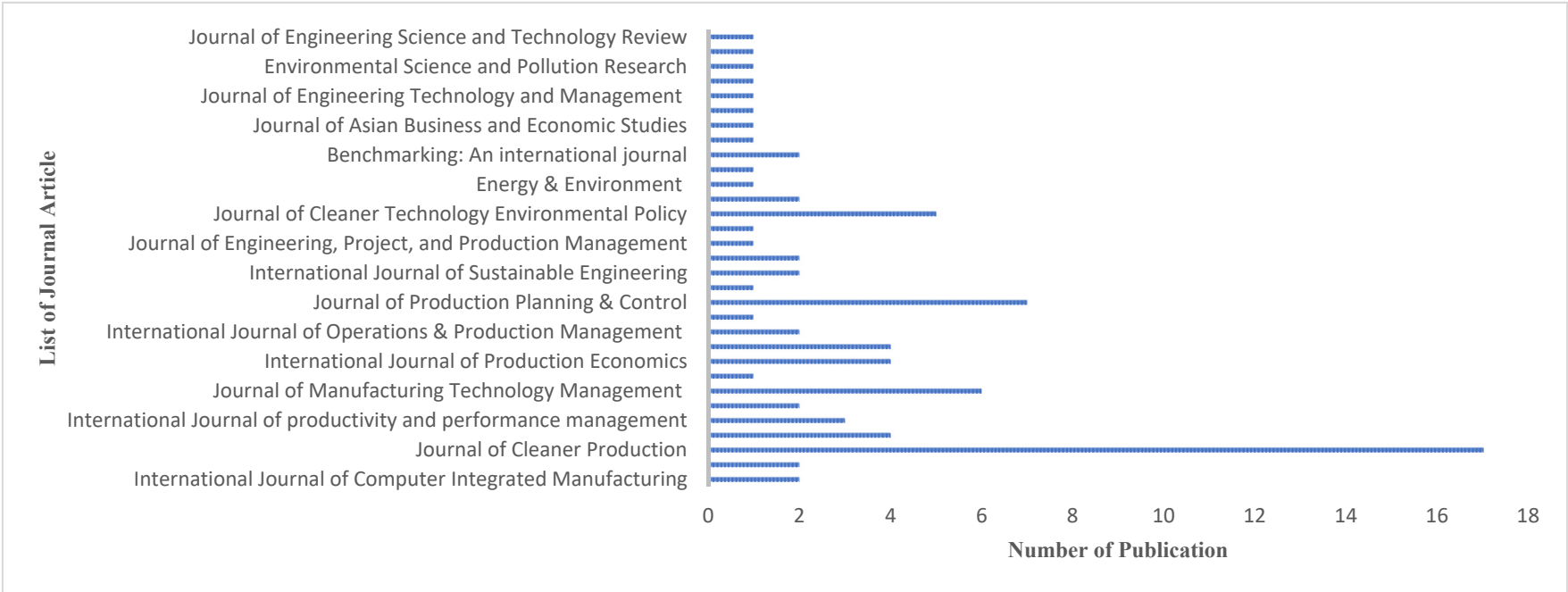


Figure 3. Journal articles categorisation.

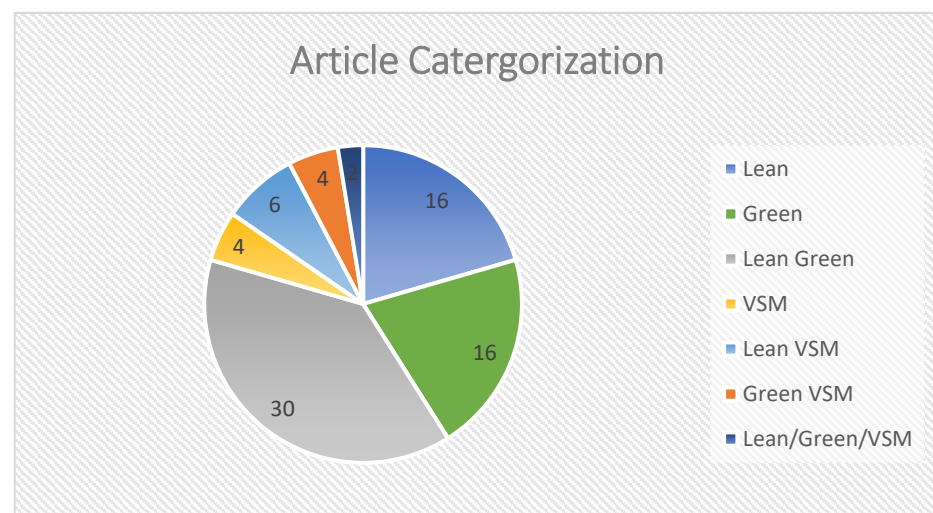


Figure 4. Article categorization on keywords.

5. Findings, Gaps, and Directions for Future Research

The relationship between lean and green manufacturing has been examined in detail and the effects of the integration and application in any manufacturing process are positive. The review conducted reveals that there is inadequate research on the application and impact of lean and green manufacturing in developing economies such as the sub-Saharan regions of Africa.

The application of lean and green manufacturing techniques in developed economies as indicated in the literature suggest that environmental impact was reduced and cost savings of 5–30% were achieved [93,94]. Additionally, adopting these practices can help decrease greenhouse gas emissions and energy consumption. While implementing LG practices, a shift in cultural practices that is geared toward improvement is required. In the field of technological advancement and innovation, sub-Saharan manufacturing companies need to collaborate with suppliers and research institutions to improve the quality of products, enhance efficiency and productivity and optimise the supply chain to gain access to emerging markets.

Under the following sub-heading, the gaps and direction of future research have been highlighted to encourage future researchers and facilitators that implement these strategies to research.

5.1. Performance Measurement System

A number of performance measurements have been highlighted by several works of literature to include metrics and measurement systems but there is a lack of this integration within the SSA automotive industry impeding sustainable achievement.

5.2. Application of Lean Green Manufacturing in the Sub-Sahara Automotive Industry

Due to the global environmental concern and competitive pressure among manufacturers, the need for manufacturers to improve their operational performance and the green outcome becomes prevalent. However, since the adoption of lean and green practices has not been fully explored by many SSA auto manufacturers due to the barriers highlighted in the paper, the industry continues to underperform. Countries such as Nigeria and Kenya have mostly been affected by government policies that supported imports, leading to poor industrialisation. Hence, the management of various companies that play a vital role in the implementation of these practices should explore comprehensively the role of lean and green practices in resolving the organisational challenges of the manufacturing industry within the SSA region.

In Nigeria, the automotive industry comprises all tiers of suppliers. Many manufacturing companies have a larger percentage of their process focused on assembly operations. Due to globalisation, supply chain activities have become very complex with manufacturing companies sourcing their materials from other countries resulting in very high lead times causing the industry to struggle. Enshrining the concept of lean thinking by the Toyota production system coupled with green practices resolves the majority of the barriers facing the Nigerian auto industry as highlighted in Table 9.

In addition, to sustain lean-green practices in sub-Saharan Africa, a tailored-centered approach that considers the context and challenges of the region should be considered. Practical steps that can be initiated can range from as suggested by [28]

1. **Leadership Commitment:** Strong commitment and support from top-level management to initiate the implementation of lean-green practices are necessary. Allocating resources for training, infrastructure improvement, and change management initiatives will contribute to a sustainable lean culture and practice.
2. **Build Knowledge:** Educating employees about lean principles, their methodologies, and benefits is essential to sustaining lean-green principles. Additionally, conducting workshops and training programs will build an understanding and develop a culture of continuous improvement.
3. **Respect Employees:** Employee involvement and empowerment are key to sustaining lean initiatives. Employees should engage in problem-solving, process improvement, and decision-making to foster knowledge sharing.
4. **Gemba Walks:** This involves leaders of organisations going to the workplace or shop floors to observe processes, identify waste, and engage with employees in resolving them. This practice promotes a good level of understanding of the work environment and encourages continuous improvement.
5. **Partnership with suppliers:** Collaboration with suppliers, customers, industry associations, and research institutions accelerates the implementation of lean and green practices and creates a supportive ecosystem.
6. **Continuous Improvement Culture:** A culture of continuous improvement, where employees are encouraged to identify and address waste. Additionally, important to recognise and reward employees for their contributions to lean initiatives.
7. **Monitor and Measure Performance:** Establishing key performance indicators (KPIs) to track and measure the impact of lean-green practices. Regularly monitoring progress, analysing data, and having data-driven decisions for continuous improvement.

5.3. Manufacturing Industry Service Sector

Many works of literature that address the prevalent issues of the manufacturing industry in Africa, consistently mention the barriers and challenges of adopting sustainable practices within the industry but are yet to explore the opportunities that lean and green practices which have played an integral role in the success of many western auto manufacturers to which the SSA region depend on for import of automobiles and other service parts.

5.4. Economic Dimension

The integration of lean-green practices into the manufacturing industry can have both negative and positive impacts on a company's economic performance. Some of the key economic implications could range from initial implementation costs, increased efficiency and productivity, and improved competitiveness to consumer demand.

Although implementing these practices in the manufacturing sector can be expensive at the early stages, many manufacturing companies within the SSA region still need to make changes to their operations in order to achieve profitability such as investing in new technologies, employee training, and process change.

5.5. Environmental Dimension

The integration of lean-green technology into the manufacturing industry can pose significant environmental risks. This is why companies that operate in this sector should take the necessary steps to minimise their impact. Some of the key steps in this dimension would range from reduced waste, reduced emissions, protection of biodiversity, and improved sustainability. Within the SSA region, manufacturing companies can reduce waste by improving the efficiency of their production. In addition, Companies can reduce their emissions of pollutants, such as greenhouse gases, by improving their energy efficiency and reducing the use of toxic chemicals in the production process.

Although lean-green technology can help companies reduce their environmental impact, it is also important to note that its effects on the environment will vary depending on the practices that are used. This is why it is important that companies thoroughly consider the various factors that affect the environment when it comes to implementing this practice.

5.6. Social Dimension

The integration of lean and green practices contributes to social reforms in the manufacturing industry, particularly in the area of health and safety, staff skills, and leadership roles in the industry. From the experience of industry workers in SSA, the facilitators (Management) are constantly failing in this aspect. Hence, a comprehensive reform within industries must be realised for operational improvement and sustainability to occur.

6. Conclusions, Limitations, Challenges, and Future Perspectives

The literature review on lean, green, and the sustainability of the manufacturing industry in Sub-Saharan Africa, presents the barriers and limitations to integrating lean and green practices within the industry. This review also presents a number of drivers and tools available for integration to improve the manufacturing process at all levels. Overall, the key to critical success which is inadequate in the current practice of lean and green in Sub-Saharan African manufacturing industries are strong leadership and commitment, involvement of all stakeholders, training, and education, continuous improvement, integration with business strategy, and use of appropriate tools and technologies. Lean and green initiatives require strong leadership and commitment from top management; involvement of all stakeholders including employees, customers, suppliers, and regulators; providing training and education to employees to ensure that they have the knowledge and skills necessary to implement the initiatives. A culture of continuous learning and improvement, with regular assessments and adjustments to the initiatives ensures that the initiatives are aligned with the organisation's goals and objectives and use appropriate tools and technologies, such as lean and green metrics and sustainability software to track progress and identify areas for improvement in order to be successful. Hence, the facilitators of this type of improvement in this region must carefully consider while selecting appropriate tools that resolve existing challenges.

Lean and green are two separate concepts that can contribute to the potential benefit of synergistic effect when implemented together. Lean has a business philosophy that aims to maximise customer value while minimizing waste which involves identifying and eliminating non-value-adding activities, streamlining processes, and continuously improving operations. By implementing lean practices, organisations can increase efficiency, reduce costs, and improve the overall effectiveness of their operations while green refers to environmentally sustainable practices that aim to minimise the negative impact of an organisation's activities on the environment. This can involve reducing energy and water consumption, reducing waste and pollution, and using eco-friendly materials and processes.

When lean and green practices are implemented together, they can create a synergistic effect, which means that the combined impact is greater than the sum of the individual impacts. For example, by streamlining processes and reducing waste, an organisation can not only increase efficiency and reduce costs but also reduce its environmental impact. This

can lead to multiple benefits, including increased competitiveness, improved reputation, and reduced risk of regulatory non-compliance.

The implementation of lean and green integrated practices in the supply chain can have a number of positive influences and challenges of interaction including:

1. **Improved efficiency:** Lean practices such as just-in-time (JIT) inventory management and value stream mapping can help identify and eliminate non-value-adding activities, reducing lead times and improving overall efficiency. Green practices such as eco-efficient sourcing and transportation can also help reduce waste and improve efficiency.
2. **Cost savings:** By streamlining processes and reducing waste, organisations can reduce their operating costs and improve profitability. Green practices such as energy-efficient logistics and using eco-friendly materials can also help reduce costs.
3. **Increased competitiveness:** Adopting lean and green practices can help organisations differentiate themselves from their competitors and attract customers who value sustainability.
4. **Improved reputation:** Implementing lean and green practices can enhance an organisation's reputation as a responsible corporate citizen, which can promote customer loyalty and a positive brand image.
5. **Risk reduction:** Implementing lean and green practices can help organisations mitigate environmental, regulatory, and reputational risks associated with their operations.
6. **Improved supply chain resilience:** Lean and green applications can improve the flexibility and adaptability of supply chains, making them more resilient to disruptions such as natural disasters or changes in market demand.

Other areas where the lean and green implementation can influence part of the future perspective are Industry 4.0 and 5.0.

Industry 4.0, also referred to as the Fourth Industrial Revolution, is the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and automation into manufacturing and other industries while Industry 5.0, also known as the Fifth Industrial Revolution, is a term that has been used to describe the integration of emerging technologies such as quantum computing, nanotechnology, and biotechnology into manufacturing and other industries. It incorporates the integration of advanced technologies with the unique skills of human workers to enhance productivity, innovation, and customization. This strikes a balance between automation and human involvement.

The implementation of lean and green practices in the context of Industry 4.0 and Industry 5.0 can have a number of positive influences, including improved efficiency, cost saving, increased competitiveness, improved reputation, risk reduction, and enhanced technological innovation where the integration of emerging technologies such as quantum computing, nanotechnology, and biotechnology can be used to support lean and green practices.

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