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Sustainability-Oriented Application of Value Stream Mapping: A Review and Classification

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ABSTRACT Notwithstanding the research on refining lean tools for the sake of sustainable development is slowly progressing, sustainability-oriented application of value stream mapping has received undivided attention from practitioners and researchers. Going through the literature highlights that there is a lack of research in integrating and systematising the available knowledge on this lean tool, which is regarded as a visual process-based method to make sustainable progress over the time-based and green concepts of wastes to also assess and improve the societal sustainability performance of organisations. Hence, this paper has been aimed at presenting the findings of a systematic literature review on value stream mapping from the triple bottom line point of view. It classifies and codes the main studies in the context as well as provides a research agenda with nine recommendations that may advance this under-studied field. To narrow the gap in the current literature, this article also proposes a sustainability indicator set that would considerably contribute to guiding and strengthening the state-of-the-art research on successful implementation of the application. Besides, the findings indicate that more investigations are needed on employing survey and conceptual methodologies, applying comparative and cross-industry perspectives, developing sustainability indicator sets particularly societal metrics, and considering the stakeholders' benefits from adopting sustainability-oriented value stream mapping. The research on the convergence of this sustainability-oriented application and new paradigms such as IR 4.0 and/or Circular Economy should be also strengthened.

INDEX TERMS Sustainability, lean manufacturing, value stream mapping (VSM), indicator set, literature review.

I. INTRODUCTION

Given the growing global viewpoints on sustainable development as a normative reference, which is popularly outlined in the WCED report in 1987 [1] as "Our Common Future," a large number of the scientific community has been involved in advancing this phenomenon through eliminating/minimizing waste (Muda) throughout a system's value stream under the umbrella of lean philosophy. In this regard, significant attention has been directed to value stream mapping (VSM) by practitioners and researchers due to its effectiveness and compatibility [2], [3]. This application has unprecedentedly undergone numerous modifications; from the 'traditional VSM' which is employed to improve the organisational performance to the environmentally-benign VSM – 'Green VSM' [4]–[6], 'Energy VSM' [7], [8], 'Environmental VSM' [9]–[15] – then, 'Socio-VSM' [16] which is societal-based and aimed towards improving the operational and social performance, and, today, 'Sustainable VSM' [17]–[19] which integrates the traditional VSM with a sustainability metric set to visualise and assess the environmental impact and societal well-being.

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According to Rother and Shook [20], a value stream entails the production flow of a product from raw material to the finished good for the consumer, and the design flow from concept to launch with an indication of all the required actions, both value added and non-value added, to the system. Thus, VSM is a tool that presents the material and information flow from the customer's orders to the finished good to the war against Muda [21]. Gholami *et al.* [16] assert that its aim is to "identify wastes in manufacturing plants and supply chains as well as in process industries and service sectors to ultimately realign production practices with lean philosophy towards establishing future improvement plans." Sustainability-oriented VSM studies highlighted that more sustainable improvements can be achieved by decreasing the utilization of raw materials, reducing impacts to the environment, lessening solid wastes for landfill disposal, and improving societal challenges associated with the existing hazards to the health and safety of employees. Nevertheless, there is a lack of research on the integration and systemization of the available knowledge on this sustainable-extended lean tool [16]. Thus, a growing number of practitioners and researchers have proposed the need to conduct more advanced sustainability-oriented VSM studies [22], [23]. Accordingly, this paper is directed at accomplishing the following objectives using Scopus which compiles the data collected by academic databases such as ScienceDirect, Springer, Emerald, Wiley, Taylor & Francis, etc. in very extensive and systematic coverage:

- To identify the most relevant articles presenting VSM implementation from the triple bottom line (TBL) point of view;
- To classify and codify the various characteristics of the identified articles;
- To provide a summary of each article's contribution and analyse the available literature; and
- To present a research agenda and a sustainability metric set for addressing the gaps in the current knowledge of sustainability-oriented VSM.

To meet these objectives, this article outlines the research methodology in Section 2, the classification and coding method for the identified articles in Section 3, literature review in Section 4, the results and discussion on the investigated articles in Section 5, recommendation and proposal for a research agenda in Section 6, and finally, conclusions in Section 7.

II. RESEARCH METHODOLOGY

To address the objectives of the research, this paper applied a methodological approach introduced by Junior and Filho [24] and successfully performed by [25]–[28]. According to [28], this systematic approach has received undivided attention from scholars in various contexts due to its capability to characterize the studies on emerging issues through classifying and coding them and subsequently identify and illustrate the challenges for future research. As such, this review method is employed to provide the most important information for

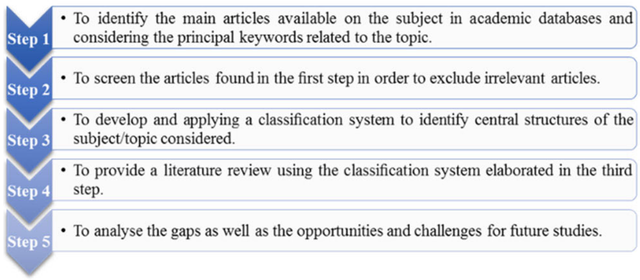

FIGURE 1. Key steps of research methodology.

practitioners and researchers in investigating issues related to sustainability-oriented VSM studies. Based on the aforementioned literature, there are five key steps in performing this review as shown in Figure 1.

The first step entails data mining which was conducted in March and April 2020 using the academic database Scopus, which is the largest indexer of global research content and includes titles from more than 5,000 publishers worldwide. The central theme in this study was research articles containing the keywords of (sustainab∗ OR green) AND ("lean") AND ("value stream map∗" OR "VSM" OR "material∗ and information flow∗") in the titles and abstracts. The general "lean" term is employed as a referential concept and the truncated search ∗ is to classify the variation of the terms as well as the state of being plural or singular. The query strings used for the search resulted in 104 documents for the first screening stage.

The screening was conducted to identify irrelevant articles to our research such as review articles (these articles contained terms including review, recent, progress, critical, revisit, advance in the title and abstract), unavailable articles, and those that did not discuss VSM from the TBL perspective. The search was also limited to journal articles and conference proceedings up until the year 2019 since the data mining was conducted at the beginning of 2020. Resultantly, 57 remaining articles were taken into careful consideration for the review from 2008 to 2019. Similar investigations have recommended a comparable number of articles for systematisation [24], [26]–[28].

The identified articles were then classified according to the coding system as presented in Table 1, which is discussed in the following section. Considering our formulated coding, a descriptive statistic was utilised to determine the main gaps in the literature, as presented in Section 5.

III. CLASSIFYING AND CODING

After identifying and screening the published studies on Sustainable-extended VSM, a classification framework was organised to effectively classify and codify 57 identified articles. This classification scheme consists of nine major themes numbered from 1 to 9 according to the leading studies [24]–[28] and the formulated objectives. Alphabetical letters (A, B, C, etc.) were used to code each of the classification

TABLE 1. Classifying and coding framework.

Classification	Meaning	Coding
1	National Context	A – Developed country B – Developing country C – Not applicable
2	Sustainability-oriented VSM Focus	A – VSM and only environmental issues B – VSM and only societal issues C – VSM and socioeconomic issues D – VSM and economic and environmental issues E – VSM and sustainability (triple bottom line) issues F – Not applicable
3	Research Method	A – Single case study B – Multiple case studies C – Survey D – Conceptual E – Mixed approach (es)
4	Industry	A – Manufacturing B – Non-manufacturing
5	Analysed sector	A – Production B – Supply chain management C – Other areas
6	Sustainability-oriented VSM Map	A – Only current state map B – Current and future state map C – Only future state map D – Not applicable
7	Sustainability-oriented VSM and new paradigms	A – Sustainable manufacturing/ Sustainable operation B – Sustainable management C – Industry Revolution 4.0 D – Sustainable supply chain E – Not applicable
8	Beneficiaries of Sustainability-oriented VSM	A – Top management/managers B – Other employees C – Other stakeholders D – Not applicable

numbers. Hence, this classification is a combination of numbers and letters. Tables 1 and 2 represent the frameworks as such.

Classification 1 is related to the national context of the studies and is coded on a scale from A–C. Classification 2 identifies the focus of the sustainability-oriented VSM implementation i.e. whether it has focused on solely one dimension, two different aspects or triple bottom line; this part is coded on a scale from A–F. Classification 3 relates to the research method and is coded on a scale from A–E. Classification 4 associates with the investigated industry, whether it is manufacturing or non-manufacturing; this classification is coded on a scale from A–B. Classification 5 relates to the analysed sector, whether it is production, supply chain management or other areas. This classification is also coded on a scale from A–C. Classification 6 relates to the adoption of VSM maps including current and future state maps, and is coded from A–D. Classification 7 explores the integration of sustainability-oriented VSM implementation and new paradigms such as sustainable manufacturing and IR 4.0. This classification is coded on a scale from A–E. Classification 8 presents the beneficiaries of its implementation (scale A–D).

Classification 9 explains the economic, environmental and societal metrics which are assessed and discussed in the articles. The metrics which are just mentioned but not implemented are not included in Table 2. The classification for economic metrics is coded from A–SS, the classification for environmental metrics is coded from A–X while the classification for societal metrics is coded from A–R. The analysis of the coding will be discussed in section 5.

IV. LITERATURE REVIEW

The early research on extended VSM tools was presented in 2008 by Mason *et al.* [29] and Lai *et al.* [30] who focused on economic and environmental sustainability perspectives. Mason *et al.* [29] introduced the integration of sustainability metrics into VSM to measure and eliminate supply chain waste. Several case studies involving food industry scenarios demonstrated the capability of lean practice in waste elimination to achieve sustainability. The proposed approach contributes to the evolution of lean by supporting the development of VSM. Lai *et al.* [30] presented the introduction of a part-package VSM with mixed approaches that illustrates the process and identifies essential parameters to support life cycle environmental impact analysis (LCA), total cost analysis (TCA), and energy consumption analysis (ECA). The framework was performed in a major US automaker, taking into consideration the manager's jurisdiction; it identifies the packaging design and logistics procedure, and comprises both cost and environmental impacts. The study also provides a framework for integrated Material Flow Analysis in supporting the concept of TCA, LCA, and ECA to ensure data consistency in packaging system assessment [30].

In 2009, Torres and Gati [10] presented the implementation of Environmental VSM (EVSM) to associate with the economic and environmental issues prevalent in the manufacturing process. The case study was performed in an alcohol and sugar manufacturing company in Brazil. The EVSM contributes to the investigation on losses structure and the approaches to reduce environmental impacts. This mapping tool visualises environmental management and hence provides recommendations to enhance green performance for overall improvement. Subsequently, Ramakrishnan *et al.* [9] implemented Energy VSM with mixed approaches to evaluate energy consumption in the production process of a high-end server manufacturing company. The degree of greenness is assessed and represented in the form of an alphanumeric indicator, whereby the alphabets represent the degree of energy usage and the numbers represent the ease of implementing the opportunity. On this basis, the "Energy Kaizen" framework provides an indicator of the degree of lean and determines the actions to eliminate waste. The identified actions are inserted into a discrete event simulation model to analyse the impact of selected changes on energy wastes and other indicators such as cycle time, rate of production, and resource utilisation rates.

Paju *et al.* [31] developed an assessment method based on VSM application, known as Sustainable Manufacturing

TABLE 2. Classification 9 – classifying and coding the metrics.

Classification	Coding
Applied economic metric	A – Value-added time B – Non value-added time C – Value-added cost D – Non value-added cost E – Cycle time F – Takt time G – Product lead time H – Changeover time I – Uptime J – Downtime K – Scrap rate L – Overall Equipment Effectiveness (OEE) M – Raw material/Material cost N – Energy cost O – Labour cost P – Machine hour rate Q – Labour hour rate R – Fuel oil cost S – Speed loss T – Machining cost U – Machine time V – Labour time W – Total defect products/defect rate X – Ordering time Y – Holding time/Delay time/Waiting time/Idle time/stoppage time Z – Work in progress (WIP) AA – Holding cost BB – Natural gas cost CC – Transportation cost DD – Inventory cost EE – Processing cost FF – Setup time GG – Waste cost HH – Water bill cost II – Transportation time JJ – Lead cost KK – Transportation Overall Vehicle Effectiveness (TOVE) LL – Maintenance cost MM – Takt cost NN – Stock cost OO – Overall Environmental Equipment Effectiveness (OEEE) PP – Chemical cost QQ – Throughput time RR – Rework cost SS – Inspection cost
Applied environmental metric	A – Water usage B – Power consumption C – Raw material consumption for process D – Heat loss E – Carbon footprint F – Chemical consumption G – Air acidification H – Water eutrophication I – Energy consumption for process J – Energy consumption for transportation K – Energy consumption on maintaining facility environment L – Ratio of use of renewable energy (%) for process M – Ratio of use of renewable energy (%) for transportation N – Chemical emission O – Chemical spills P – Oil and grease usage Q – Natural gas consumption for process R – Natural gas consumption for transportation S – Harmful gases release T – Noise level in the environment U – Oil and coolant consumption V – Water quality – Total Dissolved Solids (TDS) W – Dust exposure X – Oil leakage
Applied societal metric	A – Physical load index (PLI) B – Work environment risk (E- Electrical system, H-Hazardous chemicals/materials, P-Pressurized system, S- High-speed components) C – Noise level D – Days attendance and days absence (Health&Safety) E – Rapid Entire Body Assessment (REBA) F – Number of incidents/accident rate/injury rate G – Room temperature H – Absenteeism (Abs) (Number of hours absent & worked) I – Turnover rate J – Percentage of products and services assessed for improvements K – Content of substances that can cause environmental or social impact L – Demand fulfilment M – On-time arrivals N – Salary level (SLe) O – Local community hiring ratio P – Diversity ratio Q – Employee training Intensity ratio R – Product defect ratio

Mapping (SMM). SMM implementation integrates the defined sustainability indicators with mixed approaches based on VSM, Life Cycle Assessment (LCA), and Discrete Event Simulation (DES). The proposed SMM method contributes to goal definition, selection of the sustainability indicators, and illustration of the current and future state process maps. With regards to the relationship between lean and green performance, Marudhamuthu and Krishnaswamy [32] adopted several lean tools such as 5S, Value Stream Maps (VSM) and SMED to improve the process environment, enhance social sustainability, and lower the marginal cost of pollution in the Indian garment industry. The study concluded that lean production is complementary to environmental performance thus suggesting approaches to minimise waste. Lourenço *et al.* [33] published a conceptual paper proposing the Multi-Layer Stream Mapping (MSM) approach to measure and enhance the financial performance, environmental performance, and energy efficiency of a production system through a multi-variable diagram. The proposed MSM can reduce costs by eliminating non-value-added environmental issues in the process. The findings confirmed that MSM is an effective method for assessing, evaluating, and quantifying the environmental dimension in industrial plants and therefore enhance global industrial performance [33].

Due to its surging popularity and relative effectiveness, VSM has been receiving growing research interest towards achieving sustainability performance. In 2014, Faulkner and Badurdeen [18] developed Sustainable VSM (Sus-VSM) by addressing suitable metrics in measuring the environmental and societal sustainability performance of an American television satellite dish manufacturer. In the research, a set of fundamentally critical metrics were determined and visual symbols were designed for each proposed metric on the Sus-VSM to provide understandable visualisation of the sustainability measures. The authors concluded that Sus-VSM is an effective approach to illustrate sustainability performance in a production line. Following that, Brown *et al.* [17] applied Sus-VSM on various scenarios with different manufacturing systems to assess sustainability performance. The implementation of the Sus-VSM methodology in the case studies provided comparative results across three manufacturing systems to determine generalisable information. The results showed that energy consumption and value-added ratio also correlate with the nature of the product on top of the type of manufacturing system configuration. The authors concluded that Sus-VSM contributes to sustainable performance measurement by highlighting recommendations for sustainability improvement along the manufacturing process [17]. Similarly, Sparks and Badurdeen [19] implemented Sus-VSM by identifying metrics to assess economic, environmental, and societal sustainability in supply chain networks and process level. The authors adopted mixed approaches with the Discrete Event Simulation (DES) modelling on a case scenario to develop future state maps and identify potential sustainability improvements. The results showed that the future states modelled with DES are beneficial in assessing the impact of improvements and modifying strategies in order to achieve sustainability. Chiarini [34] studied the applicability of five Lean Production tools namely VSM, 5S, cellular manufacturing, Single Minute Exchange of Die (SMED) and Total Productive Maintenance (TPM) in reducing the environmental impacts of five European motorcycle component manufacturing companies. The results concluded that VSM is useful for determining the environmental impacts of production processes; 5S for reducing oil leakage and developing waste management; cellular manufacturing for reducing electricity consumption, and TPM can lead to a decrease in machine oil leakage and dust or chemical gases emission from the operating machine into the atmosphere. Folinas *et al.* [35] presented a systematic method developed from the VSM approach to assess the environmental performance of the agri-food sector's supply chain. The proposed approach was conducted in one of the biggest feed companies in Northern Greece to measure waste such as non-value-added time of production and logistics processes, and to determine water and energy consumption beyond the organisational boundaries. The research project proved that VSM is applicable to improving production and logistics operations. Matt [36] discussed the adaptation of VSM in an Italian steel construction company with the concept of lean engineer-to-order (ETO) manufacturing systems. The author concluded that mapping and investigating the superposition of multiple overlapping value streams generally benefit the ETO manufacturer in facilitating unique projects and enhancing socioeconomic aspects.

Kasava *et al.* [37] demonstrated the partial implementation of Sustainable Domain VSM (SDVSM) with mixed approaches in an aircraft maintenance process at a Malaysian airline. The authors illustrated the process using the SMMIAI methodology i.e. selecting, mapping, and measuring. Four main activities in the selected process were identified and grouped into smaller sub-activities and eventually categorised as value-adding and non-value adding activities. Sustainable manufacturing indicator repository (SMIR) was introduced as a guideline to indicate the measurable sustainability indicators at each mapped activity. A sustainability assessment was conducted by performing the Relative Assessment of Building Solutions (MARS-SC) methodology.

Numerous studies published in 2016 had proven the effectiveness of the VSM tool for improving sustainability performance. Davies and van der Merwe [38] in their conceptual paper suggested the Water and Energy Stream Map (WESM) framework for interpreting baseline water and energy demand data in the South African manufacturing industry by using statistical forecasting methodology. The authors indicated that the WESM framework can lead to an improvement in water and energy efficiency in the manufacturing industry. Edtmayr *et al.* [39] presented an approach to improve resource efficiency by integrating sustainable parameters and indicators into value stream mapping (VSM). The method was performed in the automotive industry and conducted based on process-oriented accounting of resource usage along with buffers, transportation, and processes. The findings indicated that this approach is beneficial for sustainability reporting, costs, and revenues calculation of sustainable value streams. Garza-Reyes *et al.* [40] proposed a systematic approach named Sustainable Transportation Value Stream Map (STVSM) and presented a case study by combining the transport and logistics sector to enhance the transport operations of a world-leading logistics company in Mexico. The results indicated that both operational efficiency and environmental performance of road transport operations can be improved through the deployment of the STVSM tool in the green and lean paradigms. Gregori *et al.* [11] used an integrated VSM methodology, termed as Energy VSM method (EVSM) in a household appliances manufacturing factory in Italy to assess the energy value flowing in the production system. The authors concluded that EVSM can be implemented to identify the value-added energy within the production, eliminate wasted energy, and hence enhance the sustainability of processes. Energy VSM (EVSM) was also implemented by Verma and Sharma [12] to identify non-productive energy-consuming processes in an ISO 9001-2008 certified small-scale manufacturing factory. The paper aimed to minimise the environmental impact of factory manufacturing and therefore propose a methodology for the Green Manufacturing practice. They concluded that EVSM is an effective method for determining wasted energy, and that the new design of machine tools or modifications in the existing setup can lead to a decrease in energy waste [12]. To enhance the sustainability of the Traditional Brass Industry (TBI), Karunarathna *et al.* [41] developed a decision-making framework for costing and environmental management aspects based on VSM and the mixed approach of life cycle principles. The authors conducted a case study on the brass manufacturing industry in Sri Lanka to monitor the material flow, information flow, and decision-making methods. The proposed framework can be implemented for decision-making purposes in a new design or product introduction and at the same time achieve better environmental management practices [41]. The integration of VSM and life-cycle assessment (LCA) was investigated further by Vinodh *et al.* [42] who aimed to achieve sustainable manufacturing in an Indian automotive component manufacturing company. Their findings indicated that the proposed framework is applicable for visualising and measuring the sustainability performance of the manufacturing process. They suggested that this framework contributes significantly to the identification of potential improvement opportunities for decreasing environmental impacts using conventional lean and sustainable strategies [42]. Rebouillat *et al.* [43] developed a conceptual paper aimed at studying the implementation of a related ASTM International standard in natural stone production to guide the relative understanding of sustainability and productivity in both unit process and production system levels. The ASTM standard proposes a generic representation for manufacturers to derive specific unit manufacturing process (UMP) representations as key to analyse sustainability performance. The implementation of this standard through a simple software demonstrator tool showed that it is applicable and contributes to decision making in business [43]. By adapting VSM and mixed approaches, Thanki and Thakkar [44] presented the application of value-value load diagram (VVLD) for modelling and evaluating the lean and green performance of a cylinder manufacturing firm situated in India. The integration of VSM, material flow cost accounting (MFCA), and pinch analysis methodology in VVLD provides the visualisation of resource usage, value addition, and performance improvement possibilities in the production system. The findings clarified that VVLD can be utilised to evaluate operational and environmental performance in terms of the eco-leanness index and reveal opportunities for lean and green improvement [44].

Numerous research efforts in 2017 had discussed VSM application among manufacturing operations. Helleno *et al.* [45] proposed a conceptual method by integrating a new group of sustainability indicators into the VSM tool. The proposed method was implemented in three case studies of manufacturing processes in the Brazilian industry. The developed conceptual method consisted of new indicators associated with triple bottom line aspects, and the traditional indicators of VSM (Lean KPIs) aimed to assess manufacturing processes and hence suggest continuous improvement actions (Kaizen) to achieve sustainable manufacturing. Ishak *et al.* [46] presented the application of Cleaner Production VSM (CPVSM) as a lean tool for promoting sustainability in two Small and Medium Enterprises (SMEs) in Malaysia. Apart from visualising economic and environmental wastes and implementing Kaizen activities, the study also confirmed that by implementing CPVSM, the societal benefits can be enhanced utilizing minimal cost and effort for its performance. Jaghbeer *et al.* [47] introduced a process of action steps based on the integration of the VSM method with mixed approaches such as sustainability life cycle analysis and sustainability compliance index to create roadmaps for more lean and sustainable production systems in a roller blind industry. The proposed approach is a proactive method for mitigating environmental regulations changes, health risks issues, and work environment problems. The suggested process presented some practical and handy action steps which introduced a concrete roadmap and time plan for changes. In general, this framework enhances lean and sustainability performances in the fulfilment of lean and sustainability principles. In view of the significant energy usage in manufacturing, Li *et al.* [13] and Litos *et al.* [14] investigated the application of Energy VSM tool in their studies. Li *et al.* [13] proposed an integrated Energy VSM (EVSM) tool to analyse and visualise the material, energy, and time aspects in a manufacturing system. On this basis, a generic Sankey diagram platform was built to connect with existing databases (e.g. ERP) for continuous analysis. The mixed approach EVSM Sankey tool was demonstrated in an Australian aluminium recycling company to prove its applicability in improving the economic and environmental performance in a manufacturing system. Litos *et al.* [14] presented the mixed approaches of Energy VSM (EVSM) and Life Cycle Analysis (LCA) in a flooring manufacturer in the United Kingdom for enhancing manufacturing performance. The authors proposed a management tool design approach to visualise time, energy, and material waste. They suggested that eco-efficiency improvements can be determined by merging environmental and economic perspectives in a value map. Based on a simplified energy-focused VSM, Svensson and Paramonova [48] presented systems analysis and a corresponding model to enhance energy efficiency in three different Swedish industrial case studies that consume intensive usage of electric motor systems. The proposed model promoted cross-functional worker participation in improving energy efficiency, maintenance, and production processes, aside from acting as an energy efficiency measurement tool. The study concluded that the proposed model could widen the scope of energy efficiency efforts, engage more workers within the organisation in the improvement process, and hence enhance systems efficiency. Not surprisingly, the studies by Powell *et al.* [49] and Ratnayake and Chaudry [50] demonstrated the extension of VSM to include the Lean Six Sigma concept. Powell *et al.* [49] investigated the applicability of Lean Six Sigma (LSS) in a Norwegian dairy producer for improving environmental sustainability. In the study, the lean process mapping with mixed approaches was employed to determine the type of waste in the value stream. The Six Sigma DMAIC improvement cycle was applied to determine the wastes by applying relevant Lean and Six Sigma tools such as root cause analysis, standardised work, and statistical process control (SPC). The authors presented some critical success criteria for the effective implementation of LSS to achieve environmental sustainability in fresh food supply chains. Ratnayake and Chaudry [50] utilised the mixed approaches to investigate one of the underperforming support service activities in an engineering contractor (EC) operating company. The authors used the Lean Six Sigma (LSS) concept to maintain the triple bottom line (TBL) sustainable performance in the petroleum industry. Their findings showed that VSM and value stream analysis (VSA) contribute to the identification of the barriers in maintaining TBL sustainable operations and reducing wastes in the petroleum industry. Sunk *et al.* [51] presented the developments of traditional VSM and mixed approaches in enhancing system and method competencies among individuals and organisations. The paper contributed to systematic productivity improvement, lead time reduction, and value streams sustainability achievement in manufacturing production. Its findings showed the practicality of combining VSM, lean principles, short-cyclic improvement routine, process management, and Methods-Time Measurement (MTM) to improve processes and value streams in the industry. The VSM tool has also contributed to the construction sector. Elizar *et al.* [52] performed an interview with 383 respondents on the construction project in Indonesia and discussed the concept of VSM in reducing work-time waste for smart construction management. The results concluded that VSM is an effective tool for identifying construction waste and reducing time waste towards realising a sustainable construction management system.

The rise of interest in the implementation of the VSM tool for manufacturing sustainability performance was supported by several remarkable types of research in 2018. Antomarioni *et al.* [53] suggested a method for improving process performance and evaluating the impact of operational advancements on environmental sustainability in a large Italian manufacturing company producing steel caps for food and beverage packages. The authors integrated the traditional VSM approach with several sustainability-oriented indicators such as the Environmental Performance Index (EPI), carbon dioxide emissions, electricity and methane usage, and Overall Environmental Equipment Effectiveness (OEEE). It was found that the extended VSM together with the application of Kaizen enhances efficiency performances in a production process. The results revealed that by implementing the proposed framework, lean practices can improve environmental performances with low expenses. Balaji *et al.* [54] proposed the mixed approaches of Sustainable-VSM (SUS-VSM) with Life Cycle Assessment (LCA) to assess the production process demand fulfilment from sustainability perspectives. The study suggested a method for developing sustainable value stream mapping by a matrix that was presented on the manufacturing process of Rubber Bellow. The authors commented that apart from focusing on cost reduction and capacity development, companies should also consider environmental and societal aspects to fulfil the triple bottom line requirement. Garza-Reyes *et al.* [55] employed the mixed approaches to systematically implement the Environmental-VSM (E-VSM) method based on Deming's Plan-Do-Check-Act (PDCA) improvement cycle. The proposed approach was implemented in a helical rolling process of a mining and materials multinational company. The authors concluded that the proposed method is an effective tool for enhancing the green performance of operations [55]. In another paper, Garza-Reyes *et al.* [56] surveyed 250 manufacturing organisations worldwide. Their objective was to study the impact of five essential lean methods namely just in time (JIT), autonomation, kaizen/continuous improvement, total productive maintenance (TPM) and VSM on material use, energy consumption, non-product output, and pollutant releases in manufacturing. The relationship and impact of these lean methods on environmental performance were investigated using correlation analysis and structural equation modelling (SEM). They concluded that TPM and JIT have the strongest significant relationship with environmental performance, while kaizen is only applicable to material usage and pollutant release. However, autonomation and VSM application did not show any effect on the assessed environmental performance [56]. Ishak *et al.* [57] proposed an integration of Cleaner Production (CP) sustainability measures into the altered VSM. A case study was conducted in an E-Waste recovery facility in Malaysia that mainly focuses on the copper and fibre recovery process. They concluded that CPVSM can be utilised to measure sustainability in the manufacturing line. Their findings indicated that this technique contributes to the identification of economic, environmental waste, and risk hazards. Overall, the study verified that the implementation of CPVSM will enhance the triple bottom line performance in manufacturing [57]. In another study, Lugert *et al.* [58] surveyed 170 participants from different manufacturing companies to investigate the current evaluation of VSM and determine future sustainability for global trends, especially digitalization. Their findings showed that lean methods are essential in production systems, and that most users value the merger of lean methods and Industry 4.0 solutions. Out of all the participating experts in the study, 92% agreed that further development of the VSM using digitalization is compulsory. The study indicated that the integration of VSM with simulation, and the utilization of real-time data and universal interfaces are potential technologies from VSM evolution that can overcome transformation in the business environment. Hartini *et al.* [59] proposed an integrated VSM technique with environmental and social metrics for realising sustainable manufacturing. They applied the lean and green analysis tool in a furniture company in Indonesia. Their findings confirmed that the proposed approach is beneficial for visualising and evaluating the performance of the manufacturing process from a sustainable perspective. Ikatrinasari *et al.* [60] suggested the application of sustainable VSM (SVSM) in lean and green manufacturing. The case study was conducted in the Department of Stamping of an electronic component company in Indonesia. The findings indicated that lead time can be decreased by 15% while energy usage can be minimized by replacing the TL lamp with an LED light, AC control, and airflow control for the condenser. Megayanti *et al.* [61] implemented the modified sustainable supply chain VSM (SSC-VSM) approach at two bottled drinking water companies located in Indonesia. The proposed methodology aimed to compare two selected companies and address the less efficient indicators for sustainable improvement. The results concluded that SSC-VSM is an effective sustainability tool for determining economic, environmental, and social wastage along the product supply chain. To support the Industry 4.0 concept, Phuong and Guidat [62] implemented an advanced Sustainable-VSM (SVSM) method in apparel company operating in developing countries to determine the potential issues of sustainable manufacturing in the production system. The paper discussed the implementation of Radio-frequency identification (RFID), big data, and ergonomics improvement in ensuring process sustainability. With the real-time data tracking of the RFID system, it was found that the workers can reduce the finding time from 7.2 minutes/basket to less than 2 minutes/basket. In conclusion, the proposed RFID system contributes to a more accurate forecasting of raw material demands, scrap fabric tracking and management, cycle time reduction, and physical load index (PLI) reduction.

In 2019, many investigations had extensively documented the implementation of VSM for developing sustainability in manufacturing. However, several studies [63]–[65] focused solely on environmental issues. Lorenzon dos Santos *et al.* [63] assessed the main obstacles and drivers for VSM application on environmental aspects through a survey of 35 VSM specialists. The results of the survey revealed the three most crucial barriers namely: complications in analysing all relevant data of various products in a single VSM, difficulties in comparing Sus-VSM across manufacturing systems in different contexts, and the lack of essential information on environmental issues. Meanwhile, the two most important drivers for VSM application are the essential role of VSM as a well-defined method for improvement and VSM as an efficient mapping method in shortening data collection time [63]. Shahbazi *et al.* [64] compared the application of four commonly used environmental assessment tools namely Green Performance Map (GPM), Environmental Value Stream Mapping (EVSM), Waste Flow Mapping (WFM), and Life Cycle Assessment (LCA) in assessing the material efficiency and metal scrap generation of a Swedish vehicle frame production process. The results showed that GPM enables the illustration of environmental issues as an input-output model, EVSM shows chosen environmental dimensions with production-related data and information flows for better understanding, WFM presents an analysis of material and waste flows along the waste management supply chain while LCA assists in analysing the degree of environmental impact associated with various environmental issues and hence defines prioritisation and avoids sub-optimisation. The authors concluded that a combination of tools can result in better decision-making and enhanced environmental performance and value stream in an operation. Zhu *et al.* [65] proposed a green-modified VSM (GMVSM) model by adapting carbon efficiency and carbon emission as evaluation indicators in a lean and green manufacturing system to enhance the productivity and environmental performances of a metal stamped parts manufacturing company. The proposed method analyses energy flow, time flow, material flow, and transportation flow at each step of the production process in terms of the seven wastes and converts them into carbon emission flow. On this basis, a mathematical modelling for carbon efficiency was designed to evaluate the carbon emission flow and suggest possible improvements in removing wastes. The application of GMVSM was shown to illustrate the sustainable performance and contribute to minimizing environmental impacts and improving operating performance.

Very limited studies had focused on the societal dimension of sustainability. Gholami *et al.* [16] suggested a methodology to develop Social VSM (Socio-VSM) for visualising and measuring the societal sustainability performance of a hard disc drive substrate manufacturing industry. The proposed Socio-VSM is a mapping method based on conventional VSM which integrates the identified societal metrics. The findings suggested that Socio-VSM is an essential approach in sustainability assessment as it identifies areas for further improvement through a detailed ergonomic study from a societal point of view. Meanwhile, Mora *et al.* [66] proposed a model that integrates the social sustainability assessment of external stakeholders in VSM. The proposed model was applied to an existing NGO that fabricates and delivers panelized post-disaster temporary housing in Chile. The model suggested indexes that integrate the external stakeholders' social sustainability aspect into existing processes of fabrication and delivery of housing solutions. The calculated indexes enabled the assessment of changes implemented in the processes and contributed to social sustainability in VSM. Several studies concerning economic and environmental issues were published in 2019. Astuti *et al.* [67] investigated the productivity level and environmental performance of a wood processing factory located in Indonesia and addressed the approaches for improving both aspects. The solution selected to enhance the productivity or economic indicators, environmental performance, and Green Productivity Index (GPI) value was the proposed waste handling method utilizing solid waste for planting medium. By implementing this initiative, the results indicated that productivity increased by 0.002, environmental performance improved with an environmental impact reduction of 6.292, and GPI value improved by 0.0153. The implementation of the chosen solution led to cost savings of IDR 17,700 and solid waste reduction of 72.30 kg. Choudhary *et al.* [68] applied the Green Integrated

VSM (GIVSM) as a systematic methodology for enhancing the operational efficiency and environmental performance of a packaging manufacturing company in the United Kingdom. The developed GIVSM was found to be an effective tool for identifying synergies and misalignments between lean and green waste. On this basis, the authors proposed a continuous improvement framework with sustainable procurement to solve the lean-green misalignments. The framework suggested a reinvestment in cost and carbon savings entailing sustainable procurement that consists of low carbon raw material manufacturing, sustainable energy usage, low carbon transportation, and local supplier selection. Lintang and Harwati [15] implemented a green lean manufacturing concept in an Indonesian Batik manufacturing company for energy waste and emission reduction. The authors illustrate the current Environmental VSM (EVSM) to address the issues of wastage and bottleneck process. The continuous Kaizen improvement principle and Process Activity Mapping (PAM) were adapted to reduce the highest environmental waste and energy consumption in the production process, which leads to a shorter cycle time. The simulated future EVSM shows a reduction of 3.9% in cycle time, 14% in energy consumption, and 63% in emission [15]. Mishra *et al.* [69] conducted a case study on VSM integration with simulation and sustainability software in an Indian bonnet manufacturing company to evaluate the process from lean and green perspectives. The results proved that simulation software such as ARENA can reduce errors, cost, and environmental impacts. The proposed framework was also shown to facilitate the decision-making process and act as a beneficial tool for the company in the long-term. In addition, Muñoz-Villamizar *et al.* [6] proposed a new methodology termed as the overall greenness performance for VSM (OGP-VSM) to enhance the environmental effectiveness of an automotive company situated in Spain. By adopting value-added concepts, the proposed method was able to integrate, measure, control, and improve productivity and hence achieve environmental sustainability. This study revealed the gap between productive and environmental performance. The implementation of OGP-VSM showed that environmental practices can directly impact productivity. The authors concluded that OGP-VSM has a positive impact on financial performance through the improvement in productivity and environmental performance. Saied *et al.* [70] analysed the prospective effect of lean practices in improving the productivity of a deformed rolled bar steel manufacturing company by adopting various lean and quality tools such as VSM, the 5 Whys technique, and Pareto Analysis. The proposed methodology determined the factors of losses and contributed to potential material savings of 0.56% from the total monthly production, potential savings of 26.9% in natural gas usage, an increase in production by 7.58%, and a reduction in stoppage time.

In addressing the challenges of enhancing economic, environmental and societal sustainability, Djatna and Prasetyo [71] proposed a mixed approach that integrates Sustainable VSM (Sus-VSM) with Life-Cycle Assessment (LCA) to determine the potential sustainability improvement at a food-based manufacturing company. The LCA method was applied to identify environmental issues in the production process. The results concluded that the integration of Sus-VSM with LCA contributes to the evaluation of manufacturing performance through the triple bottom line dimensions. Critical metrics calculation using the Borda Count Method (BCM) indicated that total defect product, speed-loss, and heat loss were essential and hence selected for further assessment. The 5 Whys analysis identified problems which were mostly attributable to unstable material conditions, problem filling area machinery, and operator disciplinary. Process life-cycle assessment was conducted using Simapro v. 8.0, while the Failure Mode and Effect Analysis (FMEA) was found to decrease lead time, cleaning time, and total defect product [71]. Hartini *et al.* [72] developed a mixed approach of the life cycle and VSM (LC-VSM) as a lean manufacturing method to assess sustainability in a beverage firm. The proposed technique was used to investigate all activities from the life cycle perspective, including the manufacturing process, distribution, and consumption. On this basis, LC-VSM was found to measure and improve the triple-bottom-line sustainability performance of a company both internally and externally. The results concluded that LC-VSM is an effective tool to seek the possibility of increasing value-added activities for better sustainability performance. Mohamad *et al.* [22] integrated the cleaner production (CP) technology into the VSM technique to enhance the sustainable development of an SME chromium plating company operating in Malaysia. The proposed methodology visualised the environmental and economic metrics after the Kaizen activities were conducted in manufacturing production. The outcomes of the above reviews are systematically presented in detail in Table 3 using the classifying and coding approach.

V. FINDINGS AND DISCUSSION

This section is purposed to reveal the findings from analysing the articles presented in Table 3. The findings are discussed in detail in the following sections based on the classification and coding approach, as shown in Tables 1 and 2.

A. NATIONAL CONTEXT

According to Phan and Matsui [73], the implementation of lean tools and their subsequent impacts on sustainability performance are most likely influenced by the national context. Hence, it is necessary to indicate various contexts for further investigation on the effect of lean in enhancing sustainability [74], [75]. The national contexts are classified by the following categories: "A – Developed Country," "B – Developing Country," and "C – Not Applicable." Category "C" is used to classify case studies or conceptual articles that are not country-specified. Based on the results as shown in Figure 2, most of the studies were conducted in developing countries i.e. 37% whilst 30% were dedicated

TABLE 3. The summary of the studies analysed by classifying and coding.

Year	Authors	Source Type/Name*	Context	Focus	Method	Industry	Analysed sector	VSM Maps	Applied economic metrics	Applied environmental metrics	Applied societal metrics	VSM and new paradigms	Beneficiaries of VSM
2008	Mason et al. [29]	Progress in Industrial Ecology, An International Journal	A	D	B	A (Food industry)	B	B	A,B,E,II,QQ	E	-	E	A,C
2008	Lai et al. [30]	Journal of Cleaner Production	A	D	A,E	A (Packaging)	A,B,C	A	CC,DD,EE	C,I,J	-	E	A,C
2009	Torres and Gati [10]	Conference	B	A	A	A (Alcohol and sugar)	A	A	E,EE,FF,GG	A	-	B	A,C
2009	Ramakrishnan et al. [9]	Conference	C	D	A,E	A (Server)	A	D	E,N,GG	I	-	E	A,C
2010	Paju et al. [31]	Conference	C	E	B,E	A (Steel and aluminium)	A, B	A	E,N	C,I	-	A	A,C
2011	Marudhamuthu and Krishnaswamy [32]	Journal of Engineering and Applied Sciences	B	D	A	A (Garment)	A	B	B,E,H,M,O,FF,II	-	A	E	A,B
2013	Lourenço et al. [33]	Conference	C	D	D	A	A	A	A,B,C,D,E,G,Y, EE,GG,II,JJ	I	-	E	A,C
2014	Brown et al. [17]	Journal of Cleaner Production	C	E	B	A (Satellite dishes, Dispenser cathode, Mortar fin)	A,B	A	A,E,F,G,H,I	A,C,I,J	A,B,C	A	A,B,C
2014	Chiarini [34]	Journal of Cleaner Production	A	A	B	A (Automotive)	A,B	A	-	E,I,N,X	-	A	C
2014	Faulkner and Badurdeen [18]	Journal of Cleaner Production	A	E	A	A (Satellite dishes)	A,B	A	A,E,G,H,I	A,C,I,J	A,B,C	A	A,B,C
2014	Folinas et al. [35]	International Journal of Agricultural Resources, Governance and Ecology	A	D	A	A (Agri-food)	A,B	B	A,E,G,II	A,I,K	-	E	A,C
2014	Matt [36]	Journal of Manufacturing Technology Management	A	C	A	A (Steel construction)	A,B	B	-	-	-	E	A
2014	Sparks and Badurdeen [19]	Conference	C	E	A,E	A	A,B	A	A,E,G	A,C,I,J	B,F,O, P,Q,R	A	A,B,C
2015	Kasava et al. [37]	Conference	B	E	A,E	B (Airline)	C	A	A,B,O	O	F	A	A,B,C
2016	Davies and van der Merwe [38]	South African Journal of Industrial Engineering	B	A	D	A	A	C	-	-	-	E	A
2016	Edtmayr et al. [39]	Conference	C	D	A	A (Automotive)	A	A	E,G,K,L	C	-	A,B	A,C
2016	Garza-Reyes et al. [40]	Production Planning and Control	B	D	A	B (Transport and logistic)	C	B	A,B,O,Y, II,KK	E,J,S	-	A	A,C
2016	Gregori et al. [11]	Conference	A	A	A	A (Electrical appliances)	A	A	L,N	B,E,I,K	-	A	A,C
2016	Karunarathna et al. [41]	Conference	B	D	A,E	A (Traditional brass)	A	B	A,E,G,M,N,O,R, Y,BB,CC,HH,LL	A,C,E,I,T	-	E	A,C
2016	Rebouillat et al. [43]	Conference	C	D	A,D	A (Natural stone production)	A	D	-	-	-	A	A
2016	Thanki and Thakkar [44]	Production Planning and Control	B	D	A,E	A (Cylinder)	A	D	M,N,O,EE	C,I	-	A	A,C
2016	Verma and Sharma [12]	Conference	C	A	A	A	A,B	B	A,E,F,G,H	I	-	E	A,C
2016	Vinodh et al. [42]	Clean Technologies and Environmental Policy	B	E	A	A (Automotive)	A,B	B	C,D,E,F,G, H,M,P,Q, Z, AA,EE	A,B,C,E, G,H,I,J	A,B,C	A	A,B,C
2017	Elizar et al. [52]	Conference	B	D	C	B (Construction)	A,B	A	-	-	-	B	A
2017	Helleno et al. [45]	Journal of Cleaner Production	B	E	B,D	A (Cosmetic product, Thermoplastic & Kitchen utensils)	A,B	A	E,F,G,L, MM,NN	A,B,I,S	C,F,H, I,N	A,B	A,B,C

TABLE 3. *(Continued.)* **The summary of the studies analysed by classifying and coding.**

2017	Ishak et al. [46]	Journal of Advanced Manufacturing Technology	B	E	B	A (Recycling & Chrome plating)	A	D	A,B,E	E	B	A	A,B,C
2017	Jaghbeer et al. [47]	Conference	C	E	A,E	A (Roller blind)	A	C	A,B,E, G,H,K	E,L,M,T	C,F	A	A,B,C
2017	Li et al. [13]	Conference	A	A	A,E	A (Aluminium recycling)	A	A	A,B	A,C,I	-	C	A,C
2017	Litos et al. [14]	Conference	A	D	A,E	A (Flooring)	A,B	A	A,E,G,H	C,I,J,K,Q,R	-	E	A,C
2017	Powell et al. [49]	International Journal of Lean Six Sigma	A	D	A,E	A (Dairy processing)	A,B	A	GG	C	-	D	A,C
2017	Ratnayake and Chaudry [50]	International Journal of Lean Six Sigma	C	E	A,E	B (Petroleum)	B,C	B	A,G	-	-	A	A
2017	Sunk et al. [51]	International Journal of Production Research	C	D	A,E	A (Automotive)	A	A	E,G,K,L	C	-	A	A,C
2017	Svensson and Paramonova [48]	Journal of cleaner production	A	A	B	A (Automotive, iron and steel)	A	A	E	I,K	-	A	A,C
2018	Antomarion i et al. [53]	Conference	A	D	A	A (Food packaging)	A	B	A,B,E,G, H,J,N,OO,PP	E,F,I	-	E	A,C
2018	Balaji et al. [54]	International Journal of Mechanical and Production Engineering Research and Development	C	E	A,E	A (Rubber bellow)	A	D	A,B,C,D,E,G,M,O,T,U,V,X, Y, RR,SS	A,B,C,E,I,U	A,B	A	A,B,C
2018 a	Garza-Reyes et al. [55]	Journal of cleaner production	C	A	A,E	A (Helical rolling)	A	B	N,FF	A,C,E,I,J,P,S	-	A	A,C
2018 b	Garza-Reyes et al. [56]	International Journal of Production Economics	C	A	C	A	A	D	-	-	-	E	D
2018	Hartini et al. [59]	Conference	B	E	A	A (Furniture)	A,B	A	A,B,E,G,H,W, Y,Z,FF,II	C,E,I	F	A	A,B,C
2018	Ikatrinasari et al. [60]	Conference	B	D	A	A (Electronic component)	A,B	B	A,B,G	I,J,K	-	E	A,C
2018	Ishak et al. [57]	Journal of Advanced Manufacturing Technology	B	E	A	A (E-waste recovery)	A	A	A,B,E,H,I	E	B,C	A,B	A,B,C
2018	Lugert et al. [58]	Journal of Manufacturing Technology Management	A	F	C	A	C	D	-	-	-	C	A
2018	Megayanti et al. [61]	Conference	B	E	B	A (Drinking water)	A,B	A	A,B,E,G,W,II	A,C,E,F, I,J,N,V	D	A,D	A,B,C
2018	Phuong and Guidat [62]	Conference	B	E	A	A (Apparel)	A	A	A,B,E,G,W	A,I,N,W	A,B,C	C	A,B,C
2019	Astuti et al. [67]	Conference	B	D	A	A (Wood processing)	A	D	M,N,O	A,C,E,I	-	E	A,C
2019	Choudhary et al. [68]	Production Planning and Control	A	D	A	A (Packaging)	A	B	A,B,E,G, H,I,W,Y	C,E	-	A	A,C
2019	Djatna and Prasetyo [71]	International Journal on Advanced Science, Engineering and Information Technology	C	E	A,E	A (Food processing)	A	D	A,B,E, G,S,W	D	-	A	A,C
2019	Gholami et al. [16]	IEEE Access	B	B	A	A (Hard disc drive)	A	B	E	-	B,C,E	A	A,B
2019	Hartini et al. [72]	Conference	C	E	A,E	A (Beverage)	A,B	A	A,B,E, W,Y,FF	C,J	E,G	A	A,B,C
2019	Lintang and Harwati [15]	Conference	B	D	A	A (Textile)	A	B	A,B,E,N	A,C,E,I	-	E	A,C
2019	Lorenzon dos Santos et al. [63]	Production Planning and Control	C	A	C	A,B	C	D	-	-	-	A	A
2019	Mishra et al. [69]	International Journal of Lean Six Sigma	B	D	A	A (Automotive)	A	B	A,B,E, G,L,M,Z	B,E,G,H,I,J	-	E	A,C
2019	Mohamad et al. [22]	International Journal of Agile Systems and Management	B	E	A	A (Chronium plating)	A,C	A	A,B,E,H,I	A,E,I,J	B,C	A	A,B,C
2019	Mora et al. [66]	Conference	A	B	A	B (Temporary housing)	C	A	-	-	F,J,K,L, M	E	A,C

TABLE 3. ***(Continued.)*** **The summary of the studies analysed by classifying and coding.**

2019	Muñoz-Villamizar et al. [6]	International Journal of Productivity and Performance Management	A	D	A	A (Automotive)	A,B	B	B,E,H,I	F,I,J	-	E	A,C
2019	Saied et al. [70]	Conference	C	D	A	A (Rolled bar steel)	A,B	B	E,H,J,M,Y	A,C,I,Q	-	A	A,C
2019	Shahbazi et al. [64]	Sustainability	A	A	A	A (Automotive)	A	A	E,K,L	-	-	A	A,C
2019	Zhu et al. [65]	International Journal of Computer Integrated Manufacturing	C	A	A	A (Metal stamped parts)	A	B	A,B,E, F,G	C,E,I,J	-	A	A,C

*The distribution: Journal of Cleaner Production (#7), Production Planning and Control (#4), International Journal of Lean Six Sigma (#3), Journal of Advanced Manufacturing Technology (#2), Journal of Manufacturing Technology Management (#2), Clean Technologies and Environmental Policy (#1), IEEE Access (#1), International Journal of Agile Systems and Management (#1), International Journal of Agricultural Resources, Governance and Ecology (#1), International Journal of Computer Integrated Manufacturing (#1). International Journal of Mechanical and Production Engineering Research and Development (#1), International Journal of Production Economics (#1), International Journal of Production Research (#1), International Journal of Productivity and Performance Management (#1), International Journal on Advanced Science, Engineering and Information Technology (#1), Journal of Engineering and Applied Sciences (#1), Progress in Industrial Ecology, An International Journal (#1), South African Journal of Industrial Engineering (#1), Sustainability (#1), Conference (#25).

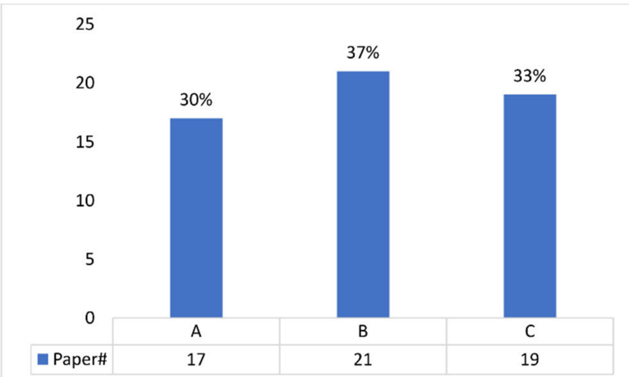

FIGURE 2. **Distribution based on the national context.**

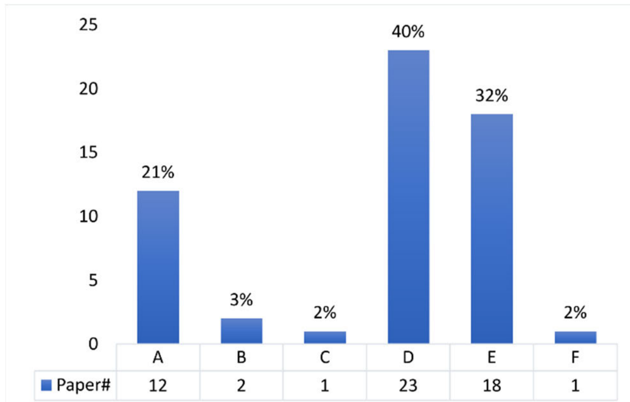

FIGURE 3. **Distribution based on the focus of the application.**

to developed countries; however, the national context which makes up 33% of the articles was not mentioned.

B. SUSTAINABILITY-ORIENTED VSM FOCUS

The second classification characterises the main sustainability-oriented VSM focus addressed in the articles. It is classified as "A – VSM and only environmental issues" whereby the VSM application in the research focused only on environmental issues. Other focuses of the application in the articles include "B – VSM and only societal issues," "C – VSM and socioeconomic issues," or "D – VSM and economic and environmental issues." The articles are classified as "E – VSM and triple bottom line issues" when the VSM application in the research investigates economic, environmental, and social performances. Finally, the article is categorised under "F – Not applicable" if the focus of the VSM implementation is not specified. As shown in Figure 3, the results indicate that most of the VSM applications in the studies focused on economic and environmental issues (40%) followed by "E – VSM and sustainability (triple bottom line) issues" with 32% and "A – VSM and only environmental issues" with 21%. From the results obtained, there are only 2 articles focusing on VSM and societal issues (3%) and just one paper focusing on VSM application in socioeconomic issues. In this context, the lack of sustainability-oriented VSM studies assessing the societal aspects may be highlighted for future research [16]. Lugert *et al.* [58] also addressed the application of VSM in the context of digitalization which can be considered for future studies.

C. RESEARCH METHODS

The methods of research used in articles are identified in this category using the following classification (Figure 4).

- "A – Single case study," frequently combined with category "D – Conceptual" and "E – Mixed Approaches";
- "B – Multiple case studies," associated with category "D – Conceptual" and "E – Mixed Approaches" in limited articles;
- "C – Survey";
- "D – Conceptual";
- "E – Mixed Approaches," for articles that combined VSM application with other methodology.

This category presents the main research methods used to demonstrate the application of VSM in assessing economic, environmental, and societal issues. The results revealed that 26 of the studies had used only one case study ("A – Single case study) which is the highest among all the methods

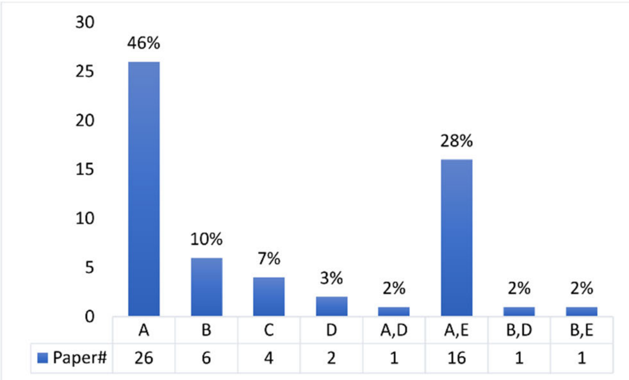

FIGURE 4. Distribution based on research methods.

(46%). The mixed approaches entailing VSM application with other methodologies such as Life Cycle Analysis (LCA), Lean Six Sigma (LSS), and other approaches in a single case study is the next most frequently used method i.e. with 16 articles (28%). This is followed by 6 articles (10%) using multiple case studies and 4 articles employing the survey method (7%). Only 2 out of 57 papers (3%) had used the conceptual method. Three articles had used a combination of more than one method. As shown in Figure 4, one article had employed a single case study with a conceptual method; another paper presented multiple case studies in a conceptual study while the last paper conducted VSM application with mixed approaches such as Sustainable Manufacturing Mapping (SMM), Life Cycle Assessment (LCA), and Discrete Event Simulation (DES) using multiple case studies [31]. Consequently, it can be noted that there is a need for research to advance sustainability-oriented VSM using further conceptual and survey methods. More creative and replicative investigations can be carried out to generate more comprehensive applications of sustainability-oriented VSM.

D. INDUSTRY

This category is related to the classification of industries mentioned in the articles. The industry is classified as "A – Manufacturing industry" or "B – Non-manufacturing industry." The results as presented in Figure 5 show that most of the articles described the application of sustainability-oriented VSM in the manufacturing industry (89%). Another 9% are conducted in the non-manufacturing industry. One survey paper presented the VSM application in both the manufacturing and non-manufacturing industry [63]. The results indicate that most of the studies implemented the application in the manufacturing sector. This supports the statement made by Sarkis that the manufacturing sector produces greater environmental impacts compared to other sectors [76].

E. SECTOR ANALYSED

This category mainly characterises the sectors analysed by sustainability-oriented application of VSM in the selected companies. The classifications include "A – Production,"

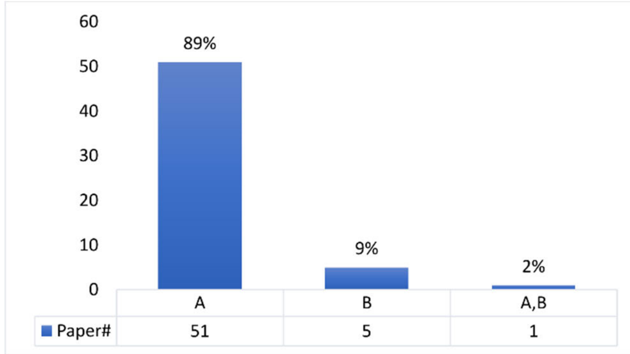

FIGURE 5. Distribution based on the industry investigated.

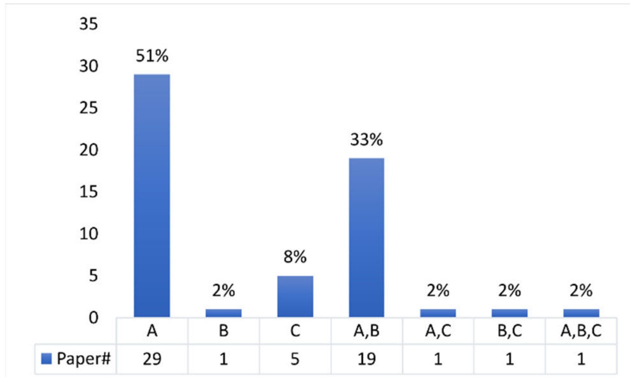

FIGURE 6. Distribution based on sector analysed.

"B – Supply chain management" and "C – Other areas." As illustrated in Figure 6, 51% of the articles analysed solely on production followed by 33% which analysed both production and supply chain management. A total of 5 papers (8%) investigated other areas besides production and supply chain management. Four papers are also identified in this category – [29] only analysed supply chain management, [22] analysed sector "A and C," [50] analysed sector "B and C" while [30] analysed all "A, B and C." According to Megayanti *et al.* [61], numerous studies have developed VSM to study the various environmental and social aspects in achieving a sustainable system; however, those studies failed to illustrate the overall sustainability performance throughout the supply chain thus highlighting the need for further research to this end.

F. SUSTAINABILITY-ORIENTED VSM MAP

This category indicates the adoption of the current and future VSM maps in assessing the economic, environmental and societal metrics discussed in the articles. The following scale is used to characterise the employment of VSM maps in this context: A – Only Current state map; B – Current and future state maps; C – Only future state map; D – Not applicable.

The analysis results as presented in Figure 7 show that 26 out of the 57 articles (46%) used only the current state map to assess sustainable performance in a company. A total

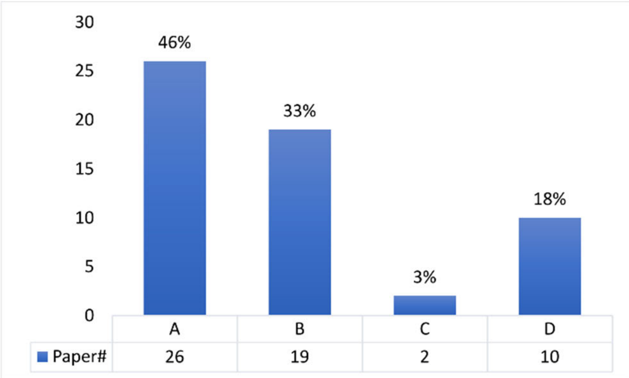

FIGURE 7. Distribution based on sustainability-oriented VSM map.

of 19 articles clearly illustrated the sustainable performance before and after improvement via both current and future state maps (33%). Two articles only showed the performances after improvement through future state map [38], [47]. However, 18% of the articles did not implement any current and future state maps. According to Rother and Shook [20], VSM is an essential step towards visualising the process flows and establishing flow transparency for the whole company. The current and future VSM maps are undeniably the most essential part of the application [16], [77] – the *current* sustainability-oriented VSM depicts the "as-is" state while *future* sustainability-oriented VSM portrays the "as-it-should-be" state [16].

G. SUSTAINABILITY-ORIENTED VSM AND NEW PARADIGMS

This category reveals the new paradigms discussed by scholars in the context. The classifications include "A – Sustainable manufacturing," "B – Sustainable management," "C – Industrial Revolution 4.0" and "D – Sustainable Supply Chain." Articles that did not discuss the implementation of VSM in any new paradigms are categorised under "E– Not applicable."

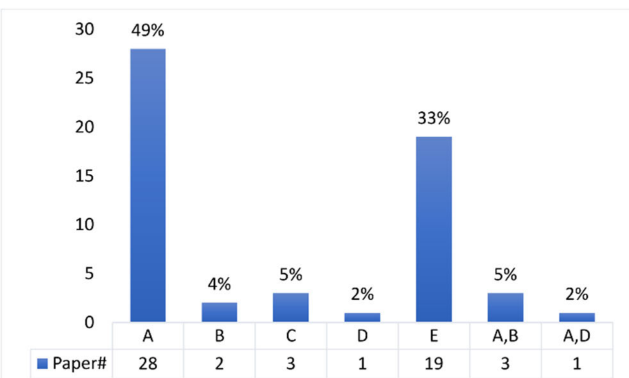

FIGURE 8. Distribution based on sustainability-oriented VSM and new paradigms.

As shown in Figure 8, most of the articles (49%) are classified under "A – Sustainable manufacturing," which necessitates "the creation of manufactured products which use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" [16]. Following that, three articles (5%) discussed the implementation of application in IR 4.0. Two articles referred to sustainable management and one article mentioned sustainable supply chain. Figure 8 illustrates that three articles also discussed both sustainable manufacturing and sustainable management while one article refers to both sustainable manufacturing and sustainable supply chain.

However, the results present that 33% of the articles did not refer to the aforementioned new paradigms. It should also be noted that there exists a research gap whereby the circular economy was not discussed in the available literature. Hence, future studies should touch on the sustainability-oriented VSM in the new paradigm of circular economy such that the investigation of [78] involved Environmental-VSM in facilitating the process of moving towards a circular business strategy or [79] that investigated how VSM can be extended to incorporate the critical aspects of circular economy. On top of that, the research on the convergence of this sustainability-oriented application and IR 4.0 should be also strengthened in future discussions for the sake of sustainable value stream development as the adoption of the IR 4.0 technologies in production will lead to greater efficiencies [62]. Although some studies have linked Industry 4.0 technologies to lean tools [e.g., [80]–[83], the convergence of these interlinks and the TBL requirements remains underdeveloped [84], [85]. According to [86], this convergence would contribute a new perspective and guides to research experts, practitioners and those who are keen to realize the benefits of this integration to transform the organizational sector into a more sustainable-based state.

H. BENEFICIARIES OF SUSTAINABILITY-ORIENTED VSM APPLICATION

Beneficiaries have been classified according to Jabbour [26], who has taken a quality managerial approach to this end:

- "A – Top Management/Managers," involved the top-level decision-makers in an operational hierarchy;
- "B – Other Employees," involved in the operational levels;
- "C – Other Stakeholders," represents the individuals such as suppliers, customers, and government;
- "D – Not applicable."

The beneficiaries of sustainability-oriented VSM application are defined according to the economic, environmental or social metrics involved in the application. The economic improvement will benefit the management; the environmental improvement will benefit the stakeholders while any social improvements will benefit the employees. The results of the analysis (Figure 9) show that most of the articles are beneficial for both top management/managers and other stakeholders (54%). Subsequently, 15 articles (26%)

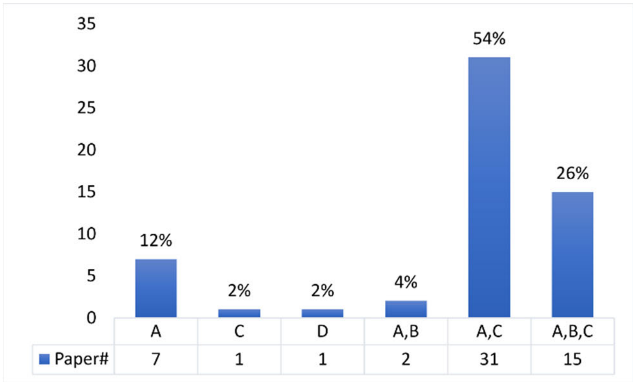

FIGURE 9. Distribution based on the beneficiaries of sustainability-oriented VSM application.

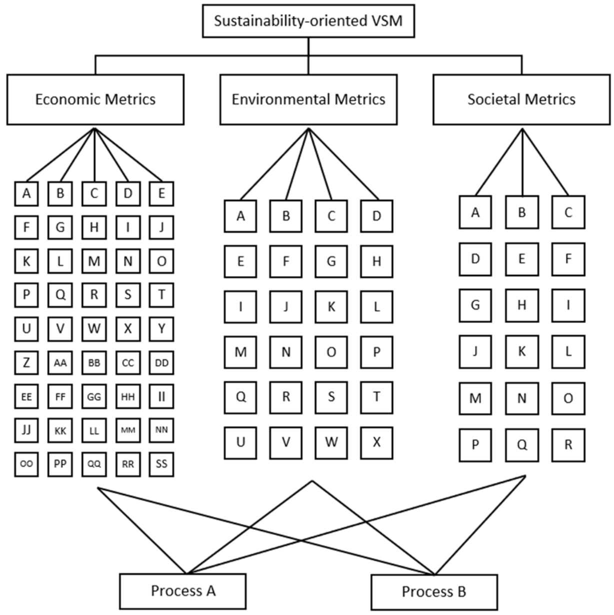

FIGURE 10. Proposed indicator set to implement sustainability-oriented VSM.

benefit all three parties. Seven articles refer solely to the top management or managers through the improvement of operational performance. Two articles are beneficial for both management and employees and one article benefits solely the stakeholders. However, it is pointed out that a sound sustainability performance report should meet the beneficiaries' needs and satisfaction [87].

I. PROPOSED INDICATOR SET

This category reveals the economic, environmental and societal indicators that had been examined, discussed and implemented in the under-reviewed articles, as presented in Table 4. These indicators can be applied for each production process (e.g., process A, process B, etc.), as shown in Figure 10, based on the organization case where the study is conducted.

Therefore, the contribution of this study also entails the establishment of an indicator set for implementing sustainability-oriented VSM, as shown in Figure 10. This sustainability indicator set includes the concrete indicators (metrics) that have been effectively applied by the state-of-the-art studies. It can be helpful in the indicators' selection process and subsequently its implementation, as there are numerous listed references that can be fruitfully exploited.

VI. FINDINGS AND PROPOSAL FOR A RESEARCH AGENDA

According to [26], [27], the analysis of the findings can determine the strengths and weaknesses of the literature and in turn present opportunities for conducting and implementing sustainability-oriented VSM studies. The results of this review have been categorized into nine classifications according to the research purpose – presenting the findings of a systematic literature review on VSM from the triple bottom line point of view – to make a valuable contribution to the body of knowledge, as most of the review papers have been revolved, almost solely, around traditional-VSM in various sectors with little or no concentration on sustainability pillars [e.g., [88]–[91]. In this context, this is also the only study that effectively applies the methodological approach introduced by Junior and Filho [24], believing that it can contribute to developing the review systems in future research agenda. Figure 11 highlights one of the merits of this approach, illustrating the most well-studied issues as well as subjects that still require further investigation, as follows.

In Classification 1, category "C" is composed of studies that did not indicate the national context of the articles, consequently requiring further consideration. Thus, *Recommendation* 1 *is to indicate the national context to compare and understand the characteristics of sustainability-oriented VSM implementation*.

In Classification 2, the majority of investigations on sustainability-oriented VSM implementation concentrated on both economic and environmental aspects. More studies are needed to investigate the societal pillar in this sustainability-oriented application. Hence, *Recommendation* 2 *is to conduct more research to develop the societal metrics in sustainability-oriented application of VSM*.

In Classification 3, the use of case studies for developing and implementing the application has been predominated; however, very few studies had incorporated research methods (categories "C" and "D") by survey and conceptual approaches. Thus, *Recommendation* 3 *is to employ the survey and conceptual methods to improve sustainability-oriented application of VSM*.

In Classification 4, the manufacturing industry (category "A") is the most frequently addressed industry in sustainability-oriented VSM studies. Hence, further research is needed to explore this application in the other organizations so as to compare them towards sustainable value stream development. Thus, *Recommendation* 4 *is to conduct sustainability-oriented VSM studies on other industries particularly those in the logistics and transport, healthcare, and*

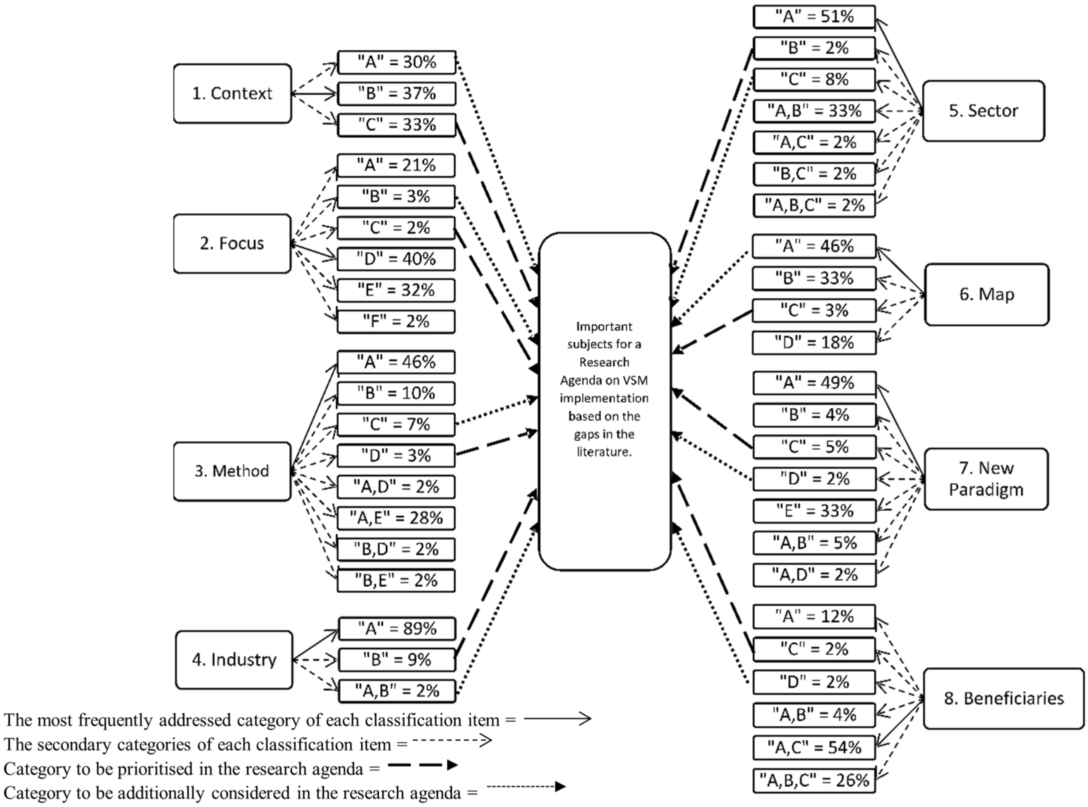

FIGURE 11. The framework of the studies analysed by classifying and coding. The percentages of articles analysed in each category have been presented.

services sectors which are currently under growing pressure to achieve sustainability.

In Classification 5, the production sector (category "A") is the most frequently discussed sector in the context; hereby, *Recommendation* 5 *is to involve further sustainability-oriented VSM studies in sustainable supply chain systems*.

In Classification 6, several articles did not employ the VSM map, and most other studies have only pictured the current state map. Thus, *Recommendation* 6 *is to illustrate both current and future state maps for better visualising and understanding sustainability-oriented application of VSM*.

In Classification 7, there was a lack of studies investigating the application in the new paradigms, as discussed in detail in Section 7. Hence, *Recommendation* 7 *is to strengthen the broad field of research on the convergence of sustainability-oriented application of VSM and the new paradigms such as IR 4.0, Circular Economy, etc. for the sake of sustainable value stream development.*

In Classification 8, which is regarding the beneficiaries of sustainability-oriented application of VSM, more studies are required to investigate the implementation of the application for individuals in category "C – Other Stakeholders" including suppliers, customers, and the government. As such, *Recommendation* 8 *is to identify and involve stakeholders to avoid any uncertainty during the implementation of sustainability-oriented application of VSM, as uncertainty is a matter especially for decision- and policy-makers.*

In Classification 9, this study has proposed an applicable indicator set for implementing sustainability-oriented VSM (Figure 10) along with numerous listed references that can be fruitfully exploited (Table 4); however, it seems glaringly scarce and in need of movement to create more significant outlook. As such, *Recommendation* 9 *is to conduct the research that contributes to elaborating the weightage of each criterion, defining how can the weightage be calculated to get a crisp number as an indicator, or presenting detailed interpretation on how to use each indicator depending on the type of process, application, and goal of decision-makers to assure sustainable performance of operations.*

VII. CONCLUSION

As sustainability-oriented application of VSM has been receiving considerable attention from practitioners and researchers and its adoption towards assessing the sustainability performance is slowly progressing, the aim of this paper is to present the framework of a literature review on the implementation of this application. In doing so, the fundamental studies in this area were classified and coded using a methodological approach. Following, a sustainability indicator set and a research agenda with nine recommendations that may advance the field were suggested after analysing

TABLE 4. Proposed indicator set to implement sustainability-oriented VSM.

TBL	Coding	Metrics	References
Economic Metrics	A	Value-added time	[12-15,17-19,22,29,33,35,37,40,41,46,47,50,53,54,57,59,60-62,65,68,69,71,72];
	B	Non value-added time	[6,13,15,22,29,32,33,37,40,46,47,53,54,57,59-62,65,68,69,71,72]
	C	Value-added cost	[33,42,54]
	D	Non value-added cost	[33,42,54]
	E	Cycle time	[6,9,10,12,14-19,22,29,31-33,35,39,41,42,45-48,51,53,54,57,59,61,62,64,65,68,69,70-72]
	F	Takt time	[12,17,42,45,65]
	G	Product lead time	[12,14,17-19,33,35,39,41,42,45,47,50,51,53,54,59,60-62,65,68,69,71]
	H	Changeover time	[6,12,14,17,18,22,32,42,47,53,57,59,68,70]
	I	Uptime	[6,17,18,22,57,68]
	J	Downtime	[53,70]
	K	Scrap rate	[39,47,51,64]
	L	Overall Equipment Effectiveness (OEE)	[11,39,45,51,64,69]
	M	Raw material/Material cost	[32,41,42,44,54,67,69,70]
	N	Energy cost	[9,11,15,31,41,44,53,55,67]
	O	Labour cost	[32,37,40,41,44,54,67]
	P	Machine hour rate	[42]
	Q	Labour hour rate	[42]
	R	Fuel oil cost	[41]
	S	Speed loss	[71]
	T	Machining cost	[54]
	U	Machine time	[54]
	V	Labour time	[54]
	W	Total defect products/defect rate	[59,61,62,68,71,72]
	X	Ordering time	[54]
	Y	Holding time/Delay time/Waiting time/Idle time/Stoppage time	[33,40,41,54,59,68,70,72]
	Z	Work in progress (WIP)	[42,59,69]
	AA	Holding cost	[42]
	BB	Natural gas cost	[41]
	CC	Transportation cost	[30,41]
	DD	Inventory cost	[30]
	EE	Processing cost	[10,30,33,42,44]
	FF	Setup time	[10,32,55,59,72]
	GG	Waste cost	[9,10,33,49]
	HH	Water bill cost	[41]
	II	Transportation time	[29,32,33,35,40,59,61]
	JJ	Lead cost	[33]
	KK	Transportation Overall Vehicle effectiveness (TOVE)	[40]
	LL	Maintenance cost	[41]
	MM	Takt cost	[45]
	NN	Stock cost	[45]

TABLE 4. *(Continued.)* Proposed indicator set to implement sustainability-oriented VSM.

	OO	Overall Environmental Equipment Effectiveness (OEEE)	[53]
	PP	Chemical cost	[53]
	QQ	Throughput time	[29]
	RR	Rework cost	[54]
	SS	Inspection cost	[54]
Environmental Metrics	A	Water usage	[10,13,15,17-19,22,35,41,42,45,54,55,61,62,67,70]
	B	Power consumption	[11,42,45,54,69]
	C	Raw material consumption for process	[13-15,17-19,30,31,39,41,42,44,49,51,54,55,59,61,65,67,68,70,72]
	D	Heat loss	[71]
	E	Carbon footprint	[11,15,22,29,34,40-42,46,47,53-55,57,59,61,65,67-69]
	F	Chemical consumption	[6,53,61]
	G	Air acidification	[42,69]
	H	Water eutrophication	[42,69]
	I	Energy consumption for process	[6,9,11-15,17-19,22,30,31,33-35,41,42,44,45,48,53-55,59,60-62,65,67,69,70]
	J	Energy consumption for transportation	[6,14,17,18,19,22,30,40,42,55,60,61,65,69,72]
	K	Energy consumption on maintaining facility environment	[11,14,35,48,60]
	L	Ratio of use of renewable energy (%) for process	[47]
	M	Ratio of use of renewable energy (%) for transportation	[47]
	N	Chemical emission	[34,61,62]
	O	Chemical spills	[37]
	P	Oil and grease usage	[55]
	Q	Natural gas consumption for process	[14,70]
	R	Natural gas consumption for transport	[14]
	S	Harmful gases release	[40,45,55]
	T	Noise level in environment	[41,47]
	U	Oil and coolant consumption	[54]
	V	Water quality – Total Dissolved Solids (TDS)	[61]
	W	Dust exposure	[62]
	X	Oil leakage	[34]
Societal Metrics	A	Physical load index (PLI)	[17,18,32,42,54,62]
	B	Work environment risk (E – Electrical system, H – Hazardous chemicals/materials, P – Pressurized system, S – High-speed components)	[16-19,22,42,46,54,57,62]
	C	Noise level	[16-18,22,42,45,47,57,62]
	D	Days attendance and days absence (Health & Safety)	[61]

TABLE 4. ***(Continued.)*** **Proposed indicator set to implement sustainability-oriented VSM.**

	E	Rapid Entire Body Assessment (REBA)	[16,72]
	F	Number of incidents/accident rate/injury rate	[19,37,45,47,59,66]
	G	Room temperature	[72]
	H	Absenteeism (Abs) (Number of hours absent & worked)	[45]
	I	Turnover rate	[45]
	J	Percentage of products and services assessed for improvements	[66]
	K	Content of substances that can cause environmental or social impact	[66]
	L	Demand fulfillment	[66]
	M	On-time arrivals	[66]
	N	Salary level (SLe)	[45]
	O	Local community hiring ratio	[19]
	P	Diversity ratio	[19]
	Q	Employee training intensity ratio	[19]
	R	Product defect ratio	[19]

the literature. This review can significantly contribute to the existing body of knowledge as there is a lack of research on the integration and systematisation of the available knowledge on this sustainable-extended lean tool. The findings include the following implications:

- Academic implications – synthesizing the literature on VSM from the TBL perspective to provide a value stream of existing ideas for creating new and better ways to understanding this application. It could strengthen sustainability-oriented VSM studies towards assessing and improving organisational sustainability performance, particularly sustainable manufacturing processes. The findings indicated that there is a need for: considering survey and conceptual methodologies, applying comparative and cross-industry perspectives, developing sustainability indicator sets particularly societal metrics, taking into account the stakeholders' benefits from sustainability-oriented VSM implementation, and further engaging the application in new paradigms such as IR 4.0 and Circular Economy for the sake of sustainable value stream development.
- Practical implications – proposing a sustainability indictor set, which has yet to be explored in the literature. This sustainability indicator set includes the concrete indicators (metrics) which were effectively applied by the state-of-the-art studies. It could help practitioners to better understand the indicators' selection process in implementing sustainability-oriented VSM. There are also numerous references presented in this article that can be fruitfully exploited.

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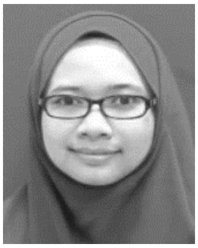

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