Sustainable Green Lean Six Sigma Methodology and Application Status: A Perspective Review

Vishwas Yadav, Pardeep Gahlot, Mahender Singh Kaswan, Rajeev Rathi, and Mahipal Singh

Abstract Green lean six sigma (GLS) is an all-inclusive methodology, assists in optimal usage of resources, minimizes wastes, and dispenses a pathway for sustainable development. The progressive manufacturing sectors are in search of approaches that will validate them to be sustainable along with yield competitive assistance. Green, lean, and six sigma strategies are some of the extensively employed tools which assist the organizations towards sustainability. The objective of this manuscript is to review the literature on GLS strategy, methodology, and successful implementation in various sectors like manufacturing, food processing, and construction, automobile, mine, and public sectors. A qualitative kind of review methodology was embraced to carry out the review. Research articles associated with GLS strategy were acquired from well-reputed journal databases. Almost thirty-five research articles from the previous seven years related to the GLS approach have been taken for this purpose. The analysis shows that a framework for the execution of GLS was instigated. The proposed GLS framework will help the manufacturing sectors through the mitigation of rejections, CO_2 emissions, and imperfections in the manufacturing processes. This review manuscript emphasizes the perception of green lean six sigma by carrying out a methodical review concerning all sectors like manufacturing, food processing, construction, automobile, mine, and public sectors and the development of a framework which is equally important from a sustainability point of view. This manuscript assists the researchers to execute GLS strategy to achieve functional and operational benefits.

Keywords Green lean six sigma · Sustainability · Framework · Lean six sigma · Six sigma

V. Yadav · P. Gahlot
Department of Mechanical Engineering, MaharashiDayanad University, Rohtak, India

M. S. Kaswan (✉) · R. Rathi · M. Singh
School of Mechanical Engineering, Lovely Professional University, Phagwara, India

1 Introduction

In recent days, each organization aims at profitability, efficiency, quality, responsiveness, customer satisfaction, and sustainability of services to protract in this era of competition in the market. The customers demand the product of high quality with minimum environmental waste, at the reasonable cost, and available with the minimum time frame [16, 26]. To meet the customer demand and governmental policies on the climate mitigation industry has to use a minimum quantity of resources, with lesser emission and societal damage. The industrial organization through the adoption of sustainable methods can take a competitive edge over the market through the production of eco-friendly, high-quality products. This will not only increase organizational competitiveness but also bring social equity and a healthy economic perspective. Continuously enhancing environmental studies have transferred the centre of attention of manufacturing sectors from conventional points, quality, a satisfaction of customers to sustainability [1, 27, 11]. Sustainability is not only to esteem the bottom line of 3P (people, plant, and profit) but also, it is the accordance of assets to face people's needs [28]. Moreover, the manufacturing sectors pay more attention to social, economic, and institutional sustainability, and it will expend more and target green actions [37]. The customer desires to buy the products that are of topmost quality, easily accessible at lower costs, and more preferable is available on time. Lean green strategy stresses on the minimal exploitation of resources through waste minimization and mitigates the harmful environmental effects through the minimization of hazardous gases. Thus, the integrated green lean strategy assists in economizing the funds, better environmental situations, and prefers social equity in the manufacturing firms as a whole. Figure 1 depicts a demand-driven model for sustainable results. There are many quality improvement approaches like statistical quality control (SQC), total quality management (TQM), and green lean six sigma (GLS) which were embraced by the organizations for sustainable improvement [46]. Out of these approaches, GLS is adduced as a budding, most effectual continuous enhancement approach. As, GLS is a comprehensive perspective that
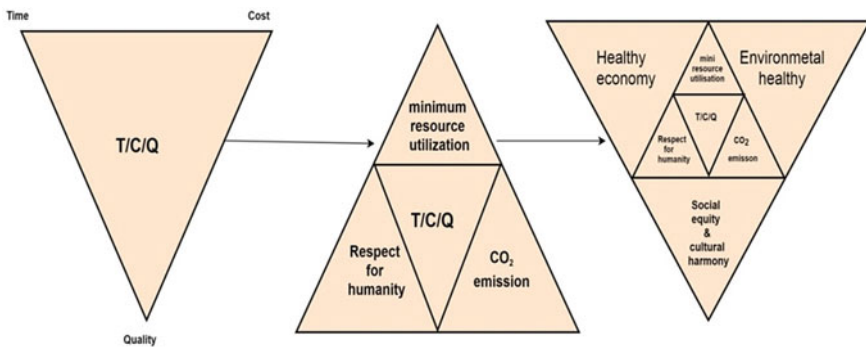

Fig. 1 Demand-driven sustainable model

minimizes the rejection along with a reduction in variation in the particular process and negative environmental impact with the help of the green concept of 3'R (recycle, reuse, and reduce) [6]. The main objective of this approach is better exploitation of natural resources, minimizes waste generation, and imparts a way for sustainable development.

GLS encompasses three different approaches that are green, lean, and six sigma to enhance productivity, profitability, manufacturing process, cycle time, and sustainability [22]. The key objective of lean manufacturing is to exhibit high-quality products or services at the bottommost cost and in the minimum time by mitigating rejections [7, 25]. The key objective of the green concept is to minimize the environmental impact of manufacturing, diminishing energy, and pollution effect of the product through consumption and recycling materials; subsequently, the product is rejected [36]. In the 1980s, six sigma was initiated by Motorola, and it was completely executed in 1988 [14]. The main goal of this concept is to modify the performance of a process and attain high-quality products or services by evaluating and abolishing the root causes of defects and reducing variation in the processes [49]. But, integrated GLS recommends a process or product that is of the best quality, cost, and eco-friendly on an account of minimization in rejection, defects, and negative environmental impacts of the product [22].

In recent days, admiration of GLS concept is increasing all over the world. Each manufacturing sector's interest is also enhanced to get full knowledge about GLS and its methodology to execute in their ventures. From the literature survey, it was cleared that most of the work was associated with the direct execution of GLS strategy. But still, the literature necessitates provision on how to pertain GLS? What should be the best methodologies and tools for all the phases? Therefore, the main objective of the present study is to perquisite GLS concepts, methodology, and execution. The current study also highlights future research guidance in this field.

2   Integration Model of Green and Lean Six Sigma

The sustainable manufacturing sector must carry out a robust on the environmental aspects. There is a great need for all manufacturing sectors to re-evaluate their entrepreneurial activities due to increased perception about sustainability and requisition for environmentally sound products [39]. Therefore, manufacturing sectors are investing more funds for the adoption of sustainable practices of manufacturing and consumption [2, 8]. The history of GLS pursued the enlargement of the lean initiative. Lean recommends for the structured exclusion of rejections over excellence at entirely stages contained by the manufacturing firms [30, 48]. The lean method minimizes rejections but it is not capable to perceive the variation in the process together mitigation in environmental impacts. Thus, the requirement of green and six sigma concept was detected to produce environmentally sound products of the higher stipulation. Green concept mitigates the harmful effects of the by-products by forming it more environmentally sound [6, 13]. But this concept is not able to detect

process variation. Thus, there is a requirement of six sigma strategy to fabricate the processes with less variation. Six sigma approach minimizes process variation that assists to reduce waste of the products [24]. GLS strategy has been adopted in organizations to create a sustainable environment and to manufacture high specification products at lower costs [12]. But a single strategy is not able to convey all the factors completely associated with sustainability [29]. Therefore, there is a great need to integrate GLS strategy that minimizes the rejection along with the reduction in variation and harmful ecological effects [17]. Also, integrated green lean six sigma strategy effectively produces high specification and eco-friendly products at the bottommost cost [15]. Therefore, incorporation of green, lean, and six sigma can be considered as the latest imminent to the manufacturing sectors for enhancement in sustainability (Fig. 2).

3 Proposed GLS Implementation Framework

Define-measure-analyse-improve-control (DMAIC) cycle is the methodology which is employed to carry out six sigma approach successfully for any venture for getting better business processes to reduce defects [10]. DMAIC cycle could dispense green lean with a explicit and comprehensive project-employed initiation to the execution and accomplishment of green strategies, which can be modified over an account of the Kaizen approach. Therefore, green approaches are executed, directed, assisted, and modified under the umbrella of six sigma's DMAIC methodology. So, this cycle helps extract and affix six sigma and lean's practices and tools throughout DMAIC's five phases when accompanying green projects. Lean and six sigma will also provide some specific techniques and tools which will be helpful to recognize define, prioritize, control, govern, protract, and modify green strategies. DMAIC cycle is the crucial methodology for directing GLS approach. Each phase of this cycle was explained as follows:

Define: This phase is very pre-eminent because it is imperative to define a suitable job for process enhancement. This phase is also used to recognize and adopt the right project additionally illuminate the scope of the project [11, 34]. The requirements, priorities, and prospects of the business and customers are intimated as voice of business (VOB) and voice of customers (VOC). The define phase helps manufacture sectors to prioritize green strategies and assets as a means to decide which organizational activity should be employed firstly and in respect of whichever variable (i.e. water consumption, energy consumption, CO_2 emissions, etc.) should be focused. Manufacturing, facilities, logistics, marketing, process, and product design, etc., are included in organizational activity/function. Six sigma recommended various specified tools which include project ranking matrix, Pareto analysis, project selection matrix, quality function deployment, Pareto priority index, analytical hierarchy process (AHP), and theory of constraints, etc.

Measure: The purpose of the measure phase is to explain the latest ceremonial of the structure and to establish the crucial aspects and matrices concerning quality
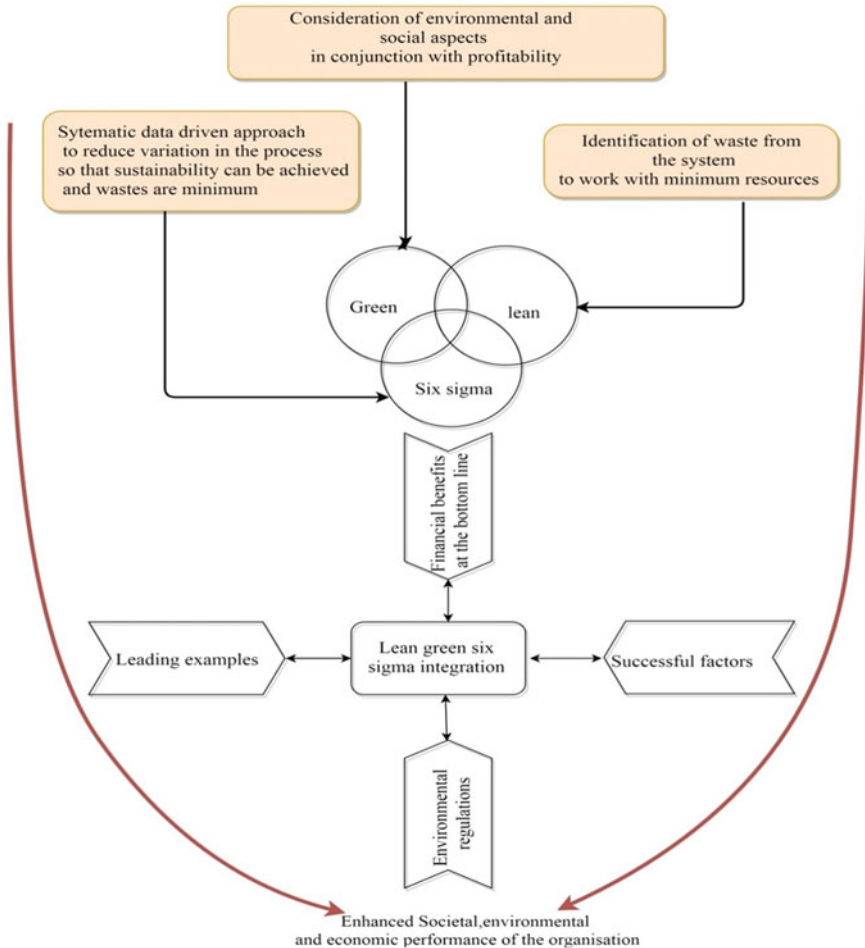
Fig. 2 Green lean six sigma model

and environment [21, 33]. Further, the target of this phase is to authenticate the root causes of the problem. In this phase, an environmental current state map has been established to dispense an exhaustive perception of the latest manufacturing process. Environmental value stream mapping (EVSM) embraces details concerning power consumption, material consumption, water consumption, and environmental effects besides traditional value stream mapping specifications like cycle time, change over time, uptime, and lead time for every practices. Environmental current state mapping development assists to visualize the genuine manufacturing trends and dispenses awareness on resource consumption from the environment. The measure phase is used to fulfil the objectives as established in the define phase.

Analyse: The purpose of analyse phase is to identify the root causes and to examine the problems and method incapability. This phase specifies enhancement pursuits that must be executed to attain process enhancements. Moreover, it studied the prospective causes of the process variation that was resulted from the measure phase. Cause and effect diagram is widely employed to point out root causes. Five-way analyses are being employed to detect the waste generation and uncontrolled utilization of water, energy, CO_2, and raw material. These tools are beneficial to identify gaps which furnish in the present operations from the foremost operations. LCA is also used in this segment to evaluate prospective green influences on behalf of all processes. The statistical analysis is also being carried out in this phase to identify the root causes of problems.

Improve: Improve phase aims at suggesting, evaluating, and executing the best possible solutions to eradicate the root cause of problems [11, 32]. There are various tools and methods like 5S, brainstorming, corrective action matrix, and poka-yoke which is used to determine the best solutions for managing waste generation as point out in the measure phase. The perspective benefits and results achieved after efficient execution must be analysed from quality and environment. Appropriate training should be provided to the industrial personnel and persons who are engaged in establishing enhancement activities. Tools like design of experiments (DOE), Kaizen, and other process enhancement methods are widely used for the enhancement in quality and productivity of an organization. A pilot test is also carried out to accomplish the performance of the improved design. Cost–benefit analysis is carried out to assess saving that is initiated from the project.

Control: Control phase aims at monitoring properly the performance improvement activities after the accomplishment of concerned [9]. All the objectives which are specified in define phase are achieved in this phase. Then, the statically process control (SPC) method can be employed to observe crucial eco-friendly dimensions such as water, energy and raw material consumption, CO_2 emissions. SPC chart will assist to monitor the parameters employed on maximum, average, and minimum consumption. Then, remedial steps were taken through SPC methodology, when the energy, water, and raw material consumption or CO_2 emissions surpasses the extreme predefined boundary. SPC will assist in the exploration and understanding of the level and causes of variation in consumption [20]. This will also help organizations in decision-making and accommodating the detection of difficulties. All enhancement activities are monitored properly but the control phase of DMAIC cycle will be suggested for the best improvement activities. It also motivates all the employees of the organization for the minimization of variability in terms of consumption of green parameters. The proposed framework applies to almost all sectors like manufacturing, food processing, mine, public sectors, construction, and automotive sectors. But, the analysis reveals that manufacturing sectors will be more benefited through the execution of this framework (Fig. 3).
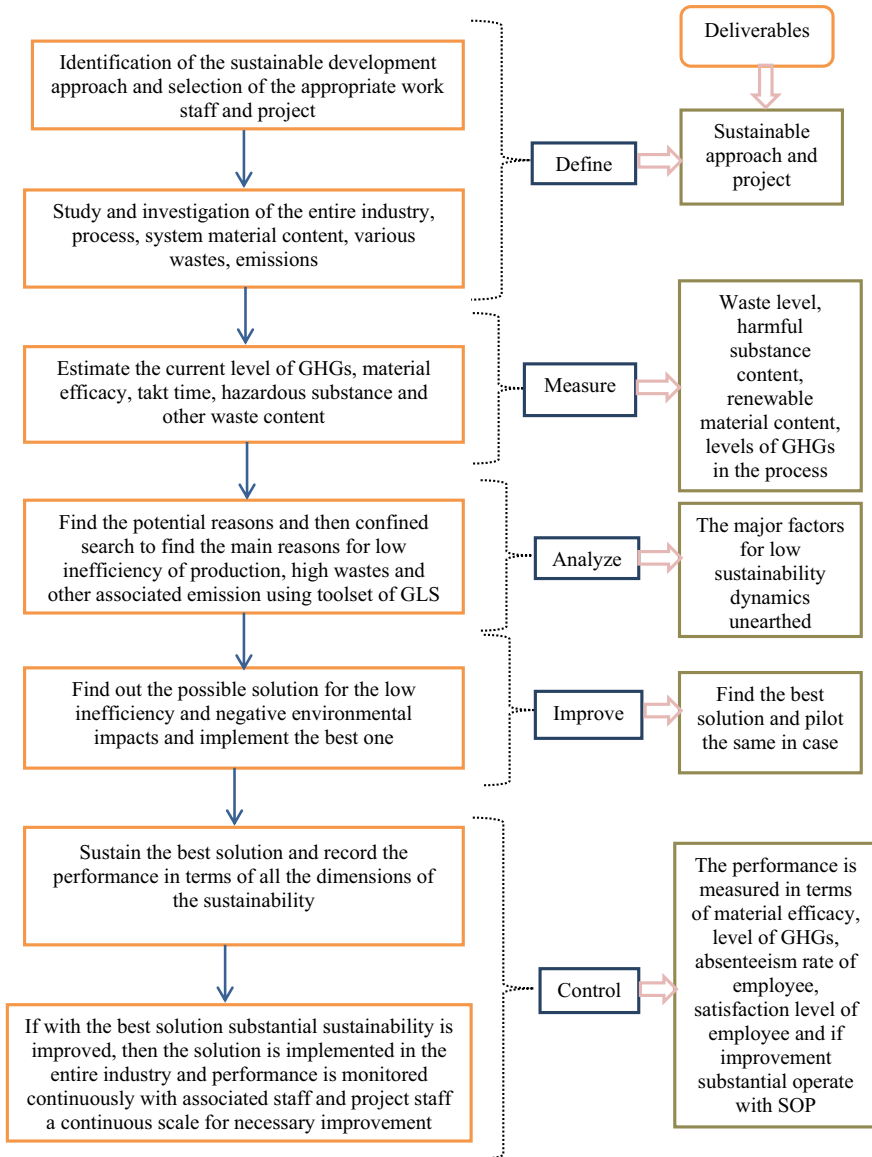
		Deliverables
Identification of the sustainable development approach and selection of the appropriate work staff and project	Define	Sustainable approach and project
Study and investigation of the entire industry, process, system material content, various wastes, emissions		
Estimate the current level of GHGs, material efficacy, takt time, hazardous substance and other waste content	Measure	Waste level, harmful substance content, renewable material content, levels of GHGs in the process
Find the potential reasons and then confined search to find the main reasons for low inefficiency of production, high wastes and other associated emission using toolset of GLS	Analyze	The major factors for low sustainability dynamics unearthed
Find out the possible solution for the low inefficiency and negative environmental impacts and implement the best one	Improve	Find the best solution and pilot the same in case
Sustain the best solution and record the performance in terms of all the dimensions of the sustainability	Control	The performance is measured in terms of material efficacy, level of GHGs, absenteeism rate of employee, satisfaction level of employee and if improvement substantial operate with SOP
If with the best solution substantial sustainability is improved, then the solution is implemented in the entire industry and performance is monitored continuously with associated staff and project staff a continuous scale for necessary improvement		

Fig. 3 GLS implementation framework

4   Current Status of GLS Implementation

The current manuscript is targeted on GLS strategy, methodology, and successful implementation in various sectors like manufacturing, food processing, construction,

automotive, mine, and public sectors. GLS is an inclusive strategy, which recommends a process or product that is of the highest quality, cost, and environment-friendly over the minimization in rejections, imperfections, and negative environmental impacts [22]. GLS is greatly dependent on six sigma's methodology that is DMAIC cycle. This cycle is employed to establish six sigma approach successfully for any project for obtaining better business processes to minimize defects [10]. Table 1 depicts green lean six sigma methodology and implementation status in various sectors. The purpose of this paper is to critically review GLS methodology and implementation status in various sectors. Almost the previous seven years research papers have been taken for this purpose. The study reveals that GLS has been successfully applied to almost all sectors like manufacturing, food processing, health care, construction, public sectors, and mines.

Some articles presented a framework for the integration and implementation of GLS strategy to improve quality and environmental effects. The objective of other research papers is to develop DMAIC-based GLS framework within the organization to obtain green objectives for a reduction in environmental impacts. Implementing GLS strategy is not an easy task in any organization. Various performance improvement GLS enablers hinder the execution of this strategy. Rest papers show that these enablers are identified to consult with the industrial personnel and extensive literature survey. Then, these enablers are validated through brainstorming sessions. Interpretive structural modelling (ISM) is also carried out to establish a contextual relationship between these enablers for the removal of them. MICMAC analysis is also employed to classify these enablers for a better understanding of them. BWM technique is also carried out to screen out top-ranked barriers for removal of them. The study reveals that manufacturing sectors faces various obstacles in the successful execution of the GLS strategy. From Table 1, it is cleared that if any organizations want to employ green lean six sigma approach effectively, they require to target these success aspects. The study reveals that after the successful implementation of GLS strategy, there will be a reduction in waste generation, process variation, and negative environmental impacts.

5   Research Gaps

GLS is an all-inclusive strategy that enhances the long-term performances of the industrial organizations over the execution of environmental assessments, manufacturing of eco-friendly products, and dispenses customer-targeted top quality products. The manufacturing sectors are forced to embrace sustainable practices like GLS due to excessive pressure of governmental policies. Therefore, humanity can be exploited through minimum environmental deterioration in terms of minimized rejections and CO_2 emissions through proper execution of GLS strategy. But, in the literature, there is no evidence of assortment of cases in which the organizational culture is not accessible to green measures. The study must be carried out for understanding the function of organizational culture in green strategies. There is no evidence to

Table 1 Green lean six sigma methodology and implementation status in various sectors

References	Sector	Remarks
[47]	Automotive sector	The aim of the article is to establish the correlation among GLS and management innovation (MI). This paper also attempts to explore how GLS can be promoted and has a pragmatic effect on the establishment of MI to attain superior performances in automotive sector. This results in a reduction in waste generation, process variation, and environmental impacts in this sector
[10]	Manufacturing sector	The purpose of the article is to provide a theoretical model for the integration of green, lean, and six sigma to enhance its effectiveness. This paper also suggests DMAIC methodology which is used to overcome the drawbacks of green lean
1	Construction sector	This article presents a framework and assimilates green, lean, and six sigma in a logical strategy with the objective of enhancing the quality and environmental effects of the construction process. This GLS framework furnishes an inclusive, multi-phase strategy for the enhancement in process, and reduction in the life cycle environmental impacts in the construction process
[13]	Manufacturing sector	The main objective of the manuscript is to pre-eminent review the green lean strategies, highlight the drawbacks, and assess the compatibility of the lean, green, and six sigma concepts. This paper also presents DMAIC methodology of six sigma approach to show that systematic literature review (SLR) specifies that integration of green lean may have assumed similar drawbacks as the independent green and lean strategies, but these may be improved on with the help of GLS approach
[4]	Manufacturing sector	This paper confers a framework that systematically directs manufacturing sectors over a five-phase and sixteen steps process to assimilate and execute GLS strategies successfully to enhance the performance of sustainability. The study reveals that averagely resource consumption and cost of energy or mass stream reduce from 20 to 40% and 7–12%, respectively, after the execution of GLS strategy
[22]	Automobile sector	The purpose of this paper is to identify barriers in GLS product development (GLSPD) from the consultation with the industrial personnel and extensive literature review. Twenty-one barriers are identified and validated by the brainstorming sessions. Then, interpretive structural modelling (ISM) has been used to instigate a hierarchical model of these barriers in executing GLSPD process in the automobile sector. Further, MICMAC analysis was also carried out to categorize for the better understanding of these barriers

Table 1 (continued)

References	Sector	Remarks
[35]	Manufacturing sector	This paper presents the successful implementation of lean six sigma framework with environmental considerations to assure the reduction in defects and environmental impacts. The study reveals that internal defects have been reduced from 16,000 to 5000 PPM. Environmental impacts were also minimized from 42 to 33 Pt
[5]	Manufacturing sector	The purpose of this article is to identify GLS barriers and to establish the contextual relationship between these barriers. Systematic literature review (SLR), interpretive structural modelling (ISM), and MICMAC analysis were also carried out for the removal of these identified barriers. Fifteen barriers were identified that hinder the execution of GLS strategy. This study can also help the industrial managers for a better understanding of these barriers to a suitable economic and environmental exhibition
[31]	Food industries	This paper highlights the application of lean six sigma and assesses the effect of LSS on environmental sustainability in food processing industries. This results in the reduction in process variation, rejections, and environmental impacts. This paper also proposed VSM-DMAIC methodology
[48]	Health care sector	This paper presents a systematic framework based on a traditional DEF meta modal, which prescribes particular aspects and synergies among lean and green approaches. This framework also assists more inspection of green supply chain in hospitals. These results in a reduction in the waste generation in the hospital operations and successfully related greening to the lean abilities may permit to reduce environmental impacts within the hospitals
[3]	Service industries	This article essentially reviews LSS methodology and emphasizes their significance to attain sustainable services. This paper also proposed a framework to identify nine critical factors, which are hindering the execution of LSS approach through sustainability. These results provide a track to obtain equity in economic, social, and environmental grades in service industries
[29]	Manufacturing sector	This paper proposes GLS strategies to identify and rank performance improvement enablers. Eighteen enablers and five enablers' dimensions are screened out from the expert's opinion and extensive literature survey. Then, AHP technique is carried out to rank these enablers and dimension enablers

Table 1 (continued)

References	Sector	Remarks
[45]	Public sector	The purpose of this paper is to provide a green lean six sigma modal for public sectors. This modal enhances the functional brilliance of public sector assistance like telecommunication, construction, and health care. GLS is integrated with supply chain management to remove obstacles withstand by public sectors, leading to process enhancement. The study reveals that the proposed modal can also apply to other public service organizations
[17]	Manufacturing sectors	The objective of this article is to identify GLS enablers, and modelling is done with the help of interpretive structural modelling (ISM) and methodically determines the relationship between these enablers. Further, impact matrix cross-reference multiplication applied to a classification (MICMAC) analysis has been employed to categorize these enablers for superior interpretation. The study reveals that twelve GLS enablers, which are hindering the execution of GLS strategy, are identified and modelled
[44]	Mine sector	The aim of the paper is to propose a framework for executing GLS approach within the organization to achieve the green objective through DMAIC process of the five aspects of the environmental exhibition. In this manuscript, a case study approach is employed to execute GLS framework to minimize the level of graphite and dust pollution in cast mine
[39]	Manufacturing SMEs	This paper presents a conceptual framework for combined green lean strategy and sustainability for small-medium enterprises. The outcome specifies that most general provocation to green lean execution is a shortage of matrices and evaluation. The outcomes are beneficial for SMEs possessor, academic persons, and industrial managers to accept measures for the improvement in sustainability
[15]	Construction sector	The objective of this manuscript is to analyses barriers to the GLS construction process through the literature survey and opinion of the experts. Further, these barriers were validated through brainstorming sessions. IMS methodology was also carried out to create 11 level hierarchical modal. MICMAC analysis is also used to classify these barriers for better understanding. The study reveals that there will be a reduction in wastage generation process variation and environmental impacts after the execution of GLS strategy in the construction industry

Table 1 (continued)

References	Sector	Remarks
[19]	Manufacturing sector	The aim of this article is to integrate and develop DMAIC-based GLS framework. The presented framework dispenses a pathway for GLS execution through a suitable preference for the project. The study reveals that many sustainability measures have been estimated with the help of unique GLS indices and toolset
[38]	Manufacturing sector	The purpose of this paper is to execute green approach into lean six sigma approach projects in manufacturing sectors. This article also recognizes under which circumstances the output of LSS projects with prudent benefits are more environmentally sound. This results in the achievement of greener, customized, and economic-oriented outcomes
[19]	Manufacturing sector	The purpose of this article is to prioritize performance improvement GLS enablers with the help of best-worst method (BWM). Twelve enablers are identified to consult with the industrial personnel. Then, the top three ranked enablers are screened out of these twelve enablers through BWM and further justified through some advanced decision-making approaches like AHP, DEMATEL, and PROMETHEE-II
[43]	Manufacturing sector	This article comprises the ranking of environmental LSS enablers with the help of best-worst method (BWM). Out of thirty enablers, twenty-two were finalized on the basis of expert's opinion and statistical analysis. The results reveal that the top-ranked enablers were beneficial for the effective execution of 'qweco-friendly LSS in any manufacturing sector. Further, the results are validated through AHP and ANP

create a questionnaire for exploration of the interrelation among GLSS operations and managerial innovation in automobile sectors. Additionally, there is no evidence in the literature that developed framework can be carried out for more manufacturing and industrial organizations where necessitate employing LSS initiatives combined with ecological issues was insistent. It can be attained by additional improvement in the current stages and proposing different tools and methods in all steps to get consistent outcomes through the developed framework. Also, the literature lacks to prioritize and ranking GLS enablers by fuzzy BWM technique and further validated by other advanced decision-making strategies like fuzzy TOPSIS and fuzzy PROMETHEE. Moreover, no evidence in the literature shows the significance of LCA in product enlargement and its prospective impact on the selection of a particular project for sustainability. Further, there is no evidence for the development of hybrid strategy of imperishable LSS execution.

6 Conclusion and Future Research Agenda

The present work carried out that is associated with various sectors like manufacturing, food processing, mine, public sectors, construction, and automotive. Green lean six sigma demonstrated to be a real business approaches that provide all-over enhancement at the level of the process. GLS has been renowned as an all-encompassing strategy that diminishes harmful environmental effects and furnishes a better quality of product simultaneously. The efficiency of the organizations has been improved after the successful implementation of GLS strategy. GLS framework will facilitate the organizations for the reduction in waste generation, process variation, and harmful environmental impacts. Averagely resource consumption and cost of energy or mass stream also reduced after the successful implementation of GLS strategy. The current study can also help the industrial managers for a better understanding of GLS barriers for suitable economic and environmental performance. The study also reveals that internal defects and environmental impacts were also reduced significantly. GLS methodology dispenses a path to obtain equity in economic, social, and environmental grades in service industries. GLS framework also reduces life cycle environmental impacts in the construction process. The organizations must employ it through the accurate methodology and take advantage of appliances and techniques for the effectual use of GLS approach. The sectors can get remarkable benefits by appropriate implementation of this strategy. To execute GLS methodology to their organizational units with greater perception, the current study will disseminate manufacturing sectors. This present study also motivates the various sectors to target on target on success factors that are significant for the success of this approach. The most of published research on the application of green and lean operations has confessed about them as an interdependent and executed strategy. In the future scope in this field, scholars and practitioners may use the application of LCA in product development and its inherent impacts on the selection of a particular project for sustainable development. Further, this study also motivates them to target the role of GLS for sustainability improvement through industry 4.0 and modelling and exploration of its performance improvement barriers. Moreover, this study animates the scholars to expect, cause, and employ sustainability to protect the environment, obtain long-term outcomes, and pertinently care for their personnel and community. Further, scholars and practitioners may think about the study of the applications of GLS methodology to the service initiatives. Moreover, if the employees of the organizations are well skilled with the procedure, this can be smoothly executed, and outcomes will reveal at the basis of supply chain management (SCM).

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