The combined implementation of Green, Lean and Six Sigma approaches for achieving environmental sustainability – A Review

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Abstract. Sectors like manufacturing, automotive, transport and logistics, etc. have greatly contributed to resource depletion all around the world. The large consumption of resources results in the rise of many greenhouse gases, waste, and other environmental problems. Organizations are now under stress to modify the way they manage their procedures and operations in response to various government environmental restrictions and the rising customer demand for ecologically friendly services and commodities. Management system approaches like green, lean and six sigma can help in achieving sustainability goals. However, no single approach is effective in achieving all sustainability goals as there are inherent limitations of these approaches. This has led people in both industry and academia to focus on the combined application of these approaches. In this paper, various research articles and case studies focusing on the combined implementation of Green, Lean, and Six Sigma methodologies for environmental sustainability across various industries is systematically summarized and reviewed. Another aim of the article is to find which combination of these approaches is best for achieving sustainability.

1. Introduction
Today the humans are facing a great many challenges which include a raging pandemic, rising population, climate change, resource shortages, and environmental degradation. Environmental waste, environmental degradation, and the loss of resources are some environmental issues. These environmental challenges pose a great threat to the existence of all living beings, their effects can be seen in the form of changing climate, scarcity of water, etc. Governments and international agencies have taken cognizance of these issues. Various agreements such as Paris Agreement 2016 and regulations both on legal and economic fronts are being discussed and notified. UN has come up with its 17 Sustainable Development Goals (SDG’s) to address these issues at various fronts. The public interest is also increasing on these issues. Now consumers show a positive attitude towards eco-friendly products, thereby increasing demand for such products [1][2]. Organizations in various sectors are adopting sustainable practices in various operational areas [3][4][5]. The use of management systems approaches like green, lean and six sigma can help to tackle this problem.

In the Green approach reduction of unfavourable ecological impacts of products and processes while improving environmental performance as an organizational strategy for businesses is done [6]. Efficiently building products for waste and pollution minimisation by parts reduction, reusing components, and rationalising the materials used [7][8][9]. Whereas, in the Lean approach elimination of eight kinds of waste which include transportation, unnecessary movement, overproduction, waiting,
processing, excess inventory, defects waste, and unused creativity in all of an organization's functional areas and its supplier network is done [10][11][12]. It was first adapted at Toyota Production System [13]. It helps organizations improve productivity and effectiveness by the reduction of waste [18] and as a result, it also improves resource efficiency and reduces environmental impact [14][15]. Common lean tools and techniques include Just-In-Time (JIT), 5S, Value Stream Mapping (VSM), Kanban, Kaizen, etc [16][13]. Six Sigma is another approach that is used to achieve sustainability goals. Traditionally this comprehensive quality improvement method has focused on reducing defects and helping companies to attain and sustain success [17][18]. It provides an operational framework in the company that explores and promotes problem solving [19]. Although the primary goal of this approach is not to reduce environmental waste, it is capable of improving environmental performance by lowering air emissions, energy consumption, and wastewater [20]. Technically, this methodology yields a failure rate of 3.4 parts per million [21]. This methodology was first introduced in the 1980s by Motorola and later refined by General Electric to improve performance and reduce costs [12]. After implementing this methodology both the companies were able to save huge sums of money [17]. This methodology has become increasingly popular over the last two decades and has been widely used in numerous organizations and different kinds of industries [22]. It uses two kinds of approaches: DMAIC (D-Define, M-Measure, A-Analyse, I-Improve, C-Control) and DMADV (D-Define M-Measure, A-Analyse, D-Design, V-Verify) [19]. The former is used for improving an already existing product or process and the latter is used for designing or implementing new products or processes, that can deliver a Six Sigma performance [13].

In recent years combining these approaches to achieve sustainability is becoming popular in research [23]. These combined approaches can help many manufacturing and service organizations to successfully achieve sustainability goals and at the same time make profits. A combination of these three methodologies i.e., Green, Lean and Six Sigma needs to be reviewed and summarised. Another objective of this article is to find which combination of these approaches is best for achieving environmental sustainability.

2. Methodology
In this literature review, Google Scholar (scholar.google.com), Taylor and Francis (tandfonline.com), ScienceDirect (sciedirect.com), and IEEE Xplore (ieeexplore.ieee.org) databases were browsed using the search words “green lean six sigma”, “lean six sigma for environment sustainability”, “Eco-lean six sigma”, and “lean six sigma for sustainability”. The literature for last the 10 years was looked into and 20 journal articles were selected for review. Inclusion criteria were to choose those research articles which proposed any framework, model, or method to combine Green, Lean, and Six Sigma approaches. Out of these most articles were from the journals ‘Production Planning & Control’ and ‘Journal of Cleaner Production’. The percentage distribution of the articles across different industries is shown in Figure 1.

![Figure 1: Percentage distribution of case studies sector wise.](image)


3. Literature Review

3.1. Green Lean Approach

As both lean and green approaches focus on eliminating waste, there exists a synergistic relationship between the two [24]. The basic difference between these two approaches has to do with the kind of waste they eliminate. In the lean approach elimination of non-value adding activities like unnecessary movement, waiting time, overproduction is done whereas in the green approach unnecessary usage of energy, natural resources, etc. is reduced [25]. Furthermore, not all lean tools are eco-friendly and can result in negative ecological effects [26]. Combining these approaches in form of models and methods can help in improving operational efficiency and environmental sustainability. A decent number of such models and frameworks have been proposed, which can be implemented in the manufacturing, automotive, agriculture, and logistics sectors.

An integrated model based on Gemba-Kaizen approach bolstered by continuous improvement approach was proposed [24]. A large aerospace manufacturing company based in the US implemented it to reduce electricity usage. It was found that there was a saving of $200,000 across six facilities over a 2-year period. It was also applied to an injection molding company and after its implementation, there was a consistent decrease in energy consumption and raw material, which resulted in a cost saving of 113,000 USD per year. A Green-Modified Value Stream Mapping (GMVSM) model was proposed for integration of Green and Lean approaches [27]. Carbon emission and carbon efficiencies were used as the evaluation indicators. The outcomes of this model were verified in a metal stamped parts producing unit and it was found that there was 39.2% and 107.4% improvement in carbon efficiency and total carbon emissions respectively. For implementing the Green-Lean approach at manufacturing cell level a 5 steps model which uses Kaizen to improve energy and mass flows was developed [28]. On an average there was a reduction in resource use between 30 to 50% after implementation. The entire cost of mass and energy flows per cell can be saved to 5-10%. Another 5-step methodology was developed in which Carbon-Value Efficiency is used as an indicator to evaluate Lean and Green performance was proposed [29]. On testing, this methodology in a metal stamped parts production plant it was found that Carbon-Value Efficiency and production lead improved by 36.3% and 64.7% respectively, and carbon footprint reduced by 29.9%. A novel tool and systematic methodology named Sustainable Transportation Value Stream Map (STVSM) for the transport and logistics sector was proposed [30]. It yielded in reduction of excess travelled distance by 57% and the fuel consumption by 13.5%. Thereby, reducing the release of CO₂, NOₓ, CO, and HC into the environment. Another systematic methodology and a novel tool named Green Integrated Value Stream Mapping (GIVSM) was proposed to achieve both environmental sustainability and operational efficiency [31]. This was applied in a packaging manufacturing SME in the U.K. to reduce carbon footprint in their packaging products. It was observed that GIVSM decreased the carbon footprint by 77% and also decreased the lead time by 63% hence increasing the operational efficiency of the company. For the agriculture sector, a framework was proposed that can be used in small and mid-size farms with the goal to enhance production and profit, and simultaneously achieving environmental sustainability [32]. Post implementing this framework, it was found that the search time for materials and tools reduced, workplace became safer and waste disposal and recycling routines improved. Also, due to improvement in work structure resource use efficiency increased.

3.2. Lean-Six Sigma Approach

Lean Six Sigma (LSS) refers to the combination of lean and six sigma approaches. It is a systematic approach that helps in quality improvement. The benefit of this approach includes reduction of defects, reworks, inventory levels, faster production, space requirement, transportation, and in waiting time [33]. It also results in increased production rate and employee motivation. LSS concepts can be effectively used to achieve environmental benefits. The manufacturing firm can profit in terms of defect reduction and variation reduction, which leads to lower resource consumption, if LSS and environmental sustainability ideas are properly aligned [34]. Achieving environmental sustainability is not the main objective of the LSS approach. Thus, in order to translate environmental opportunities
into operational excellence, adequate leveraging of LSS ideas with environmental benefit is essential [35].

A framework based on DMAIC methodology for implementing LSS to reduce environmental impact in the automotive industry was proposed [34]. After successful implementation of this framework in an Indian automotive sector there was a reduction in net power consumption, net water consumption, net coolant consumption, and the use of raw material. Also, the total number of rejections of the product was reduced from 12 to 3 units and there was improvement in sigma level from 3.60 to 4.06. A generic framework also based on DMAIC was proposed and tested on case studies from manufacturing, healthcare, and construction [36]. Post implementation it resulted in several benefits like reduction in energy usage, pollution prevention, reduction in various kinds of wastes, etc.

3.3. Green-Lean-Six Sigma Approach

Any individual or combination of any two approaches is not able to deal with all the aspect of sustainability in an organization [37]. However, these limitations can be overcome by using a combination of all the three approaches viz., Green, Lean, and Six Sigma. The Green Lean Six Sigma (GLSS) approach can assist in developing a high-quality, low-cost, and environmentally friendly process or product [6][38]. GLSS approach reduces environmental impact with the help of the 3R’s i.e., Reduce, Reuse, and Recycle [39]. It is a very promising approach which can help organizations in significantly reducing environmental impact of their products. However, only four proposed frameworks for implementing this approach were found.

A generic framework that methodically guides businesses to successfully incorporate and adopt integration of these approaches through a 5-stage and 16-steps process was proposed [4]. It was applied across different sizes industry namely (Agri-food, Textile, Tannery and Hotel), and it enabled companies to minimize their use of resources on average from 20% to 40 % and to reduce energy costs and mass streams by 7-12 %. Another generic GLSS framework that can be implemented in a methodological manner 8 steps was developed [40]. DMAIC approach was implemented in every lean cycle of this framework and organizational culture is the central tenant in this model which binds the GLSS initiatives. Green initiatives are implemented at every phase of LSS, and which results in decrease of energy consumptions, emissions, environmental costs, business waste, and will increase environmental revenues. This framework was successfully used for reducing graphite and dust pollution in an open cast mine. An integrated framework to enhance quality and improve environmental impacts of construction process was developed [17]. In this framework DMAIC methodology was used to evaluate a chosen process, to identify and measure the impact of the generated waste. Then with the help of Six Sigma tools possible reasons for the waste generation were found. For implementing GLSS approach in hospital supply chains a framework was developed [41]. This framework is based on IDEF model adjusted to healthcare setting. In this IDEF model input is the current supply chain system, the output is a leaner and greener supply chain, controls are the hospital value proposition which includes lean- six sigma philosophy and green values, and mechanism are the stakeholders and tools like 5S, VSM etc. This model helps in reducing several kinds of wastes like inventory waste, paper waste, etc. which will ultimately lead to efficient energy consumption and reduction carbon emissions.

4. Conclusion and Future Scope

Since many organizations in sectors like manufacturing, automotive, transport and logistics, etc are responsible for environmental degradation, they are under great pressure due to environmental regulations and the rise in customer demand for environmentally sustainable services and goods [24]. Using combinations of approaches like green, lean and six sigma is one best way that these organizations can achieve sustainability goals at the same time and continue to make profits. In this paper, various research articles and case studies that provided a framework for implementing Green-Lean, Lean-Six-Sigma, and Green-Lean Six Sigma across various industries for achieving environmental sustainability were reviewed. LSS being a data-driven and structured approach to eliminate sources of variation and waste surely is beneficial, but environmental waste reduction is not
its main goal. The number of articles implementing LSS for environmental sustainability is scarce, and only 2 frameworks that were verified through a case study were found. Lean-Green approach is effective achieving in sustainability goals. All Green-Lean frameworks and models reviewed resulted in a significant reduction in the use of resource consumption which in turn translated into reduction of negative environmental impact. But this combined approach inherits limitations of the individual approaches [3]. Therefore, it is recommended to integrate Six-Sigma into Green Lean approach to overcome these limitations [3]. This makes the Green-Lean-Six Sigma (GLSS), the most promising approach as it leverages the benefits of all the individual approaches and overcomes the limitation of the individual approaches. The four proposed GLSS frameworks significantly reduces the impact on environment, but there is a dearth of such frameworks. Therefore, there is need of further research in developing these types of models. The COVID-19 pandemic brought a drastic change on how various business activities are undertaken. Disruptions in the supply chain have put the existing businesses into restructuring their operations into more sustainable fashion. On demand side there is a more awareness among consumers towards more sustainable products and services. Governments across the globe are coming up with policies to address the issues of Global Warming. There is no better time to further the existing research in GLSS approach.

GLSS approach can make a profound impact across various industries. In the Manufacturing sector with emergence of Industry 4.0 researchers need to explore ways to reduce environmental waste, eliminate non-value-added activities and reduce defects to cater to the environmentally cautious consumer and in scenario where supply chain is hit globally. The automotive sector which is witnessing a momentum shift with increasing demand for electric vehicles, challenging the traditional petrol and diesel engines has helped, in India alone, a lot of EV companies are setting up. GLSS can play a major role at various steps of the product life cycle. It can be paramount in Vehicle Scrappage policy set up by Government of India 2021, which also aims at reducing prices by recycling of components in old vehicles and reducing pollution. Future research is needed for GLSS in this domain. In a world where e-commerce is at its peak, logistics is the backbone of these businesses. The increase in logistic activity in the consumer segment has also added to the carbon footprint. With the rise in e-commerce businesses, future research is needed in setting up a GLSS based network. The healthcare industry is a beneficiary of LSS, this methodology prevents medical errors. Future research is needed with application of GLSS, to address the surge in telemedicine and digitalisation in various aspects of healthcare. Globally, agriculture is a major source of pollution and over exploitation of natural resources adds to the situation. From farm to fork, a lot of carbon footprint is added. Future research is needed for the inclusion of a GLSS based approach to address the issue. The leather and textile industry are key polluters globally. The whole supply chain polluting and at most stages follows a traditional methodology. These are also water guzzlers and polluters. Future research is needed to implement the GLSS methodology in the traditional supply chain. Construction is a vital industry especially in emerging markets where the government and private players are heavily invested in the construction industry. As governments and consumers are demanding sustainability in this industry, GLSS needs to be explored in future research especially at the material procurement and execution phases where a lot of excess waste is created.

5. References

[1] Arvola A, Vassallo M, Dean M, Lampila P, Saba A, Lähteenmäki L, Shepherd, R 2008 Predicting intentions to purchase organic food: The role of affective and moral attitudes in the Theory of Planned Behaviour, Appetite, 50(2) 443-454.

[2] Schmeltz L 2012 Consumer-oriented CSR communication: focusing on ability or morality?," Corporate Communications: An Int. J. 17 (1) 29-49.

[3] Garza-Reyes, J.A 2015 Green lean and the need for Six Sigma," Int. J. of Lean Six Sigma 6(3), 226-248.
[4] Cherrafi A, Elfezazi S, Govindan K, Garza-Reyes, J.A Benhida K, and Mokhlis A 2017 A framework for the integration of Green and Lean Six Sigma for superior sustainability performance. *Int. J. of Production Research*, 55(15) 4481-4515.

[5] Erdil N.O, Aktas C.B and Arani OM 2018 Embedding sustainability in lean six sigma efforts. *J. of Cleaner Production*, 198 520-529.

[6] Sagnak M and Kazancoglu Y 2016 Integration of green lean approach with six sigma: an application for flue gas emissions. *J. of Cleaner Production*, 127 112-118.

[7] Sharma S and Vredenburg H 1998 Proactive corporate environmental strategy and the development of competitively valuable organizational capabilities. *Strategic management J.*, 19(8) 729-753.

[8] González-Benito J and González-Benito Ó 2008 Operations management practices linked to the adoption of ISO 14001: An empirical analysis of Spanish manufacturers. *Int. J. of Production Economics*, 113(1) 60-73.

[9] Schoenherr T 2012 The role of environmental management in sustainable business development: a multi-country investigation. *Int. J. of Production Economics*, 140(1) 116-128.

[10] Chauhan G and Singh T.P 2012 Measuring Parameters of Lean Manufacturing Realization," *Measuring Business Excellence*, 16(3) 57–71, 2012.

[11] Kanigolla D, Cudney E.A and Corns S.M 2013 Employing project-based learning in Six Sigma education. *J. for Quality and Participation*, 36(1) 34-38.

[12] Cudney E.A, Venuthurumilli S.S.J, Materla T and Antony J 2020 Systematic review of Lean and Six Sigma approaches in higher education. *Total Quality Management & Business Excellence*, 31(3-4) 231-244.

[13] Amitkumar D.M and Gajanan S.P 2019 "A methodical literature review on application of Lean & Six Sigma in various industries," *Australian J. of Mechanical Engineering*.

[14] King A.A and Lenox M.J 2001 Lean and green? An empirical examination of the relationship between lean production and environmental performance. *Production and operations management*, 10(3) 244-256.

[15] Aguado S, Alvarez R and Domingo R 2013 Model of efficient and sustainable improvements in a lean production system through processes of environmental innovation. *J. of Cleaner Production*, 47 141-148.

[16] Chiarini A 2017 Environmental policies for evaluating suppliers' performance based on GRI indicators. *Business Strategy and the Environment*, 26(1) 98-111.

[17] Banawi A and Bilec M.M 2014 A framework to improve construction processes: Integrating Lean, Green and Six Sigma. *Int. J. of Construction Management*, 14(1) 45-55.

[18] Sperl T, Ptacek R and Trewn J 2013 Practical lean Six Sigma for healthcare: Using the A3 and lean thinking to improve operational performance in hospitals, clinics, and physician group practices. MCS Media.

[19] Parast M.M 2011 The effect of Six Sigma projects on innovation and firm performance. *Int. J. of Project Management*, 29(1) 45-55.

[20] Farrukh A, Mathrani S and Taskin N 2020 Investigating the Theoretical Constructs of a Green Lean Six Sigma Approach towards Environmental Sustainability: A Systematic Literature Review and Future Directions. *Sustainability*, 12(19) 8247.

[21] Banuelas R, Antony J and Brace M 2005 An application of Six Sigma to reduce waste. *Quality and Reliability Engineering Int.*, 21(6) 553-570.

[22] "Improve the Extrusion Process in Tire Production Using Six Sigma Methodology," in *Procedia*
Manufacturing, 2017.

[23] Chiarini A 2017 Environmental policies for evaluating suppliers’ performance based on GRI indicators. Business Strategy and the Environment, 26(1) 98-111.

[24] Cherrafi A, Elfezazi S, Hurley B, Garza-Reyes J.A, Kumar V, Anosike A and Batista L 2019 Green and Lean: a Gemba–Kaizen model for sustainability enhancement. Production Planning & Control, 30(5-6) 385-399.

[25] Duarte S and Cruz-Machado V 2013 Modelling lean and green: A review from business models. International Journal Of Lean Six Sigma, 4(3) 228–250.

[26] Sartal A, Martinez-Senra A.I and Cruz-Machado V 2018 Are all lean principles equally eco-friendly? A panel data study. J. of Cleaner Production, 177 362-370.

[27] Zhu X.Y, Zhang H and Jiang Z.G 2020 Application of green-modified value stream mapping to integrate and implement lean and green practices: A case study. Int. J. of Computer Integrated Manufacturing, 33(7) 716-731.

[28] Pampanelli A.B, Found P and Bernardes A.M 2014 A Lean & Green Model for a production cell. J. of Cleaner Production, 85 19-30.

[29] Ng R, Low J.S.C and Song B 2015 Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric. J. of Cleaner Production, 95 242-255.

[30] Garza-Reyes J.A, Villarreal B, Kumar V and Molina Ruiz P 2016 Lean and green in the transport and logistics sector— a case study of simultaneous deployment. Production Planning & Control, 27(15) 1221-1232.

[31] Choudhary S, Nayak R, Dora M, Mishra N and Ghadge A 2019 An integrated lean and green approach for improving sustainability performance: a case study of a packaging manufacturing SME in the UK. Production planning & control, 30(5-6) 353-368.

[32] Barth H and Melin M 2018 A Green Lean approach to global competition and climate change in the agricultural sector— A Swedish case study. J. of cleaner production, 204 183-192.

[33] Albliwi S, Antony J, Lim S.A.H and Van der Wiele T 2014 Critical failure factors of Lean Six Sigma: a systematic literature review. Int. J. of Quality & Reliability Management,31(9) 1012-1030

[34] Ben Ruben R, Vinodh S and Asokan P 2017 Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study. Production Planning & Control, 28(15) 1193-1211.

[35] Cherrafi, A., S. Elfezazi, A. Chiarini, A. Mokhlis, and K. Benhida 2016 The Integration of Lean Manufacturing, Six Sigma and Sustainability: A literature review and future research directions for developing a specific model. J. of Cleaner Production, 139 828-846.

[36] Erdil N.O, Aktas C.B and Arani O.M 2018 Embedding sustainability in lean six sigma efforts. J. of Cleaner Production, 198 520-529.

[37] Pandey H, Garg D and Luthra S 2018 Identification and ranking of enablers of GreenLean Six Sigma implementation using AHP. Int. J. of Productivity and Quality Management, 23(2) 187-217.

[38] Kumar S, Luthra S, Govindan K, Kumar N and Haleem A 2016 Barriers in green lean six sigma product development process: an ISM approach. Production Planning & Control, 27(7-8) 604-620.

[39] Sreedharan V and Raju R 2016 A systematic literature review of Lean Six Sigma indifferent industries. Int. J. Lean Six Sigma 7 (4) 430–466.

[40] Sony M and Naik S 2020 Green Lean Six Sigma implementation framework: a case of reducing
graphite and dust pollution. *Int. J. of Sustainable Engineering*, 13(3) 184-193.

[41] Zhu Q, Johnson S and Sarkis J 2018 Lean six sigma and environmental sustainability: a hospital perspective. In Supply Chain Forum: *An Int. J. Taylor & Francis* 19(1) 25-41.