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An Integrated Framework for Identifying Enablers and Barriers of Lean, Green, and Six Sigma Practices Toward Sustainability in Indian Manufacturing

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Abstract: *The increasing globalisation of business and growing environmental and social concerns have compelled corporations to make their business practices more sustainable. In this disruptive market scenario, one possible solution would be to adopt and include sustainable processes and practices to improve operational, environmental, and social performance. To address such issues, manufacturing industries must deploy lean manufacturing, green manufacturing, and Six Sigma strategies. Manufacturing industries can adopt lean, Green and Six Sigma (LG&SS) to improve operational, social, and environmental efficacy. This research focuses on the adoption of integrated lean, green and Six Sigma strategies to achieve sustainability in the Indian manufacturing industry. A literature study was carried out to determine the current state of lean, green, and Six Sigma practices, and responses from Indian manufacturing SMEs were obtained to analyse the level of implementation of strategies and tools. According to an analysis of the literature, integrated LG&SS is considered as an emerging field for Indian academicians since they have published the highest number of research articles. Based on the information acquired from manufacturing SMEs on the extent to which lean, green, and Six Sigma strategies have been adopted, it is clear that six sigma has been adopted poorly compared to lean and green manufacturing strategies. The barriers of the LG&SS were initially analysed due to the poor adoption of the strategies. Based on the literature review, eighteen barriers to implementing integrated LG&SS in the Indian manufacturing industry were identified. The ISM method was used to determine the interdependence of barriers. Additionally, barriers were categorised using the fuzzy- MICMAC method as driver, linkage, autonomous, and dependent. It is found that "weak legislation" is an important barrier to LG&SS adoption in the Indian manufacturing industry, as it is at the bottom of the ISM model. Six barriers were identified as drivers, whereas four were identified as linking barriers.*

Keywords: Lean, Six Sigma, Green Strategy, ISM Approach

I. INTRODUCTION

The Indian manufacturing industry is at its apex, thanks to the "Make in India" campaign, which has pushed foreign conglomerates to relocate their manufacturing facilities to India. Governmental schemes such as the National Manufacturing Policy, which intends to increase manufacturing's Gross domestic product (GDP) contribution to 25% by 2025, are contributing to helping the nation move closer to Industry 4.0 (IBEF, 2023). The pollution level has increased, and the number of resources available for usage has decreased due to the expansion of manufacturing industries for global competitiveness, leading to global warming, climate change, and environmental degradation. As a result, the manufacturing industry must adopt strategies that reduce pollution and waste while stimulating economic growth and conserving natural resources (Maruthi & Rashmi, 2015).

Finding ways to succeed that are compatible with and supportive of social and environmental sustainability is one of the most challenging issues companies today must deal with. Lean manufacturing, green manufacturing, and Six Sigma integration can be viewed as potential remedies (Garza-Reyes, 2015a).

The Machine That Changed the World by Womack and Jones (1990) introduced the notion of lean. Lean is a Japanese manufacturing methodology that eliminates "Muda" to enhance operational effectiveness and customer happiness. Since 1990, LM has captured the interest of researchers. Researchers and practitioners have studied the definitions of lean manufacturing. Lean is a production-line management strategy that shortens the time between customer orders and delivery (Womack et al., 1990). The primary focus of lean manufacturing is detecting and eliminating waste from the production line (Dailey et al., 2004). In Lean manufacturing, waste is defined as overproduction, wait time, transportation, over-processing, inventory, motion, and defects (Dailey et al., 2004). It has evolved into an integrated system that incorporates work teams, just-in-time (JIT), management techniques, cellular manufacturing, quality systems, etc. (Shah & Ward, 2007). Lean encourages continuous development and equips businesses with the flexibility to adapt to future market demands and environmental changes (Bhamu & Sangwan, 2014; Souza & Alves, 2018).

According to the definition of the term "green," it means "interested with or supporting environment and aiming to protect environmental integrity by adopting recyclable, biodegradable, nonpolluting, and eco-efficient" (Merriam Webster Dictionary, 2023). The GM paradigm results from technological advancement and consumer demand. As a result of the new green movement, there is a greater awareness of environmental dangers worldwide, influencing new customer demands in many nations (Deif, 2011). Implementing green products, cutting emissions, employing biodegradable materials, and adopting other practices like lean manufacturing, zero emissions, and Environmental Management Systems (EMS), including ISO 14000 and ISO 14001(Dilip Maruthi & Rashmi, 2015). The integrated Lean, Green and Six Sigma concept was first presented by Banawi and Bilec (2014a) for the construction process. Garza-Reyes et al. (2014) discussed the need for Six Sigma and the connections, contrasts, and challenges of lean and green manufacturing. The lean paradigm is praised for its capacity to find waste, but it cannot measure the environmental impact on its own (Bhamu et al., 2013). Green and Lean can work together to discover waste and assess its environmental impact, but they must offer a practical approach or methodology to minimise waste (Garza-Reyes et al., 2014). Six Sigma provides the capacity to close the gap using the DMAIC approach. Due to the complementarity between Lean Green and Six Sigma, each paradigm can reduce the drawbacks of the other (Garza-Reyes, 2015a).

II. RELATED WORK

Pandey et al. (2018) identified and ranked the eighteen enablers for the organisation using a literature review and experts' opinions using the AHP method. Raval et al. (2018) identified the enablers of lean Six Sigma and developed the hypothetical model using ISM and Fuzzy MICMAC analysis. Kaswan and Rathi (2020b) identified the twelve enablers model and classified the enablers using Fuzzy MICMAC analysis. Singh et al. (2021) analysed and ranked the lean Six Sigma with aspects related to the environment using the Best Worst Method. Parmar and Desai (2020) identified the enablers for implementing Sustainable Lean Six Sigma by Fuzzy DEMATEL method for the electric parts manufacturing industry. Yadav et al. (2021) recognised the enablers for GLSS strategy and tools for the manufacturing industry. Many researchers have worked to integrate lean green, Six Sigma, and sustainability to achieve good results. Using integrated LG&SS strategies is still expanding and developing nations like India must adopt this approach. Lack of understanding of enablers is one of the reasons this kind of strategy has yet to be embraced. Very few researchers have explained LG&SS's integrated methodology. The literature review aimed to identify the enablers of LG&SS in light of the lack of research in LG&SS.

According to Dora et al. (2016), a barrier is a constraint on organisation management that prevents the adoption of novel strategies. Due to this, developing countries need help implementing LG&SS (Kumar et al., 2016). For the LG&SS strategy to be implemented successfully, it is necessary to recognise and eliminate these barriers (Ben Ruben et al., 2018; Garza-Reyes et al., 2018; Kumar et al., 2016). The barriers slow down the growth rate and make it more challenging to execute toward the implementation. Therefore, these barriers must be identified and removed to accelerate growth before implementing LG&SS. Kumar et al. (2016) ISM and MICMAC analysis were used to

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determine the twenty-one barriers to green lean Six Sigma product development. The barriers to successfully implementing lean practices for sustainable business implementation in SMEs were identified by Caldera et al. (2019).

TABLE 1 Summary of crucial paper in each stream

Authors (Year)	Type of Paper	Methods/ Technique/ Data Collection	Key findings
First steam: a need for lean, green, and Six Sigma			
Garza-Reyes (2015a)	Review	Systematic literature review	The study enables researchers to gain a deeper and broader understanding of the concurrent implementation of operational improvement and ecological initiatives and aids professionals in developing more practical deployment techniques.
Kumar et al. (2015)	Empirical	Brainstorming meetings, questionnaire-based surveys, statistical evaluation,	The 'Sustainable Green Lean Six Sigma '-related critical success factors (CSFs) have been rated.
Gholami et al. (2021)	Empirical	value stream mapping	The results showed that a DMAIC-based strategy that worked well for ecological value stream mapping should be standardised and made more efficient to accomplish environmental sustainability.
Second steam: Various sectors implemented LG&SS			
Belhadi et al. (2020)	Empirical (Manufacturing)	Hybrid Factorial Analysis Structural Equation Modeling	Verify that Big Data Analytics (BDA) has a direct adverse effect on ecological performance (EP) and also includes green and lean Six Sigma are crucial bridging factors that function as an accelerator for the indirect impacts of BDA on EP
Hussain et al. (2019)	Empirical (Construction)	Brainstorming meetings, questionnaire-based surveys, ISM, MICMAC	An 11-level hierarchal model was created using ISM methods. The findings demonstrate that GLS is less effective in unpredictable political environments, the absence of government legislation, a lack of consumer engagement and understanding of LG&SS, a lack of resources, and the support of the upper levels.
Sagnak and Kazancoglu (2016)	Empirical (flue gas emissions)	Measurement System Analysis and Gage Control	Six Sigma can overcome the limitations of lean and green. Adverse ecological effects of firms' products or services by improving environmental effectiveness by combining lean, green, and Six Sigma.
Singh et al. (2021)	Empirical (MSMEs)	Exploratory Factor Analysis, Best Worst Method	According to the study's findings, environmental enablers are second to strategic enablers in importance.
Sreedharan et al. (2018)	Empirical (Public Sector)	Questionnaire-based surveys	Black belts and supply chain professionals have identified the benefits of merging ecological supply chain leadership with Lean Six Sigma. As a result, the challenges the

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			public sector faces are eliminated, resulting in efficiency improvement.
Fatemi and Franchetti (2016)	Empirical (Manufacturing)	Questionnaire-based surveys	According to a study, using the Sustainable Lean Green Six Sigma methodology will reduce costs and environmental impact.
Third steam: Framework for the integration of LG&SS			
Cherrafi et al. (2017)	Empirical	VSM-Value Stream Mapping LCA-Life Cycle Assessment	The outcomes showed that LG&SS integration enabled organisations to reduce the cost of both mass and energy streams by 7–12% and cut their use of resources by 20–40% on aggregate.
Banawi and Bilec (2014a)	Empirical	LCA, VSM	A methodology has been established to assess the environmental effects of construction efficiency and to assist contractors in evaluating possibilities to lessen the adverse impact of their current practices and increase overall effectiveness.
Mohan et al. (2021)	Empirical	LCA and Social lifecycle assessment	Sustainability-focused LG&SS helps to reduce and improve environmental ability and process efficiency.
Gaikwad & Sunnapwar (2020b)	Empirical	Questionnaire-based surveys, Structural equation model	The anticipated result shows that integrated practices benefit businesses in terms of operating, economic, social, and environmental impact. Additionally, they provide a thorough and systematic strategy for problem-solving via continuous, gradual enhancement in the manufacturing sector.
Gandhi et al. (2021)	Empirical	ISM MICMAC analysis	"Lack of collaboration and confidence among management and workers indicates the model's highest level. "Weak legislation" is a significant obstacle to adopting LG&SS across Indian manufacturing industries.
Rathi et al. (2022)	Empirical	Questionnaire-based surveys	Integrate Industry 4.0 and Green Lean Six Sigma (GLSS) have aspects in common regarding enablers and barriers, and the combined use of methods and instruments from each methodology strengthens their shared emphasis on improving sustainability.
Fourth steam: Sustainability attained with LG&SS			
de Freitas et al. (2017)	Empirical	Questionnaire-based surveys	This study found a link between Lean Six Sigma and organizational sustainable development, primarily due to

			repercussions on the triple bottom line's economic pillar. It highlighted the importance of the cost dimension for organisational sustainability and the five impacts that influence companies the most.
Erdil et al. (2018)	Empirical	Value Stream Map	By incorporating sustainability objectives into all Lean and Six Sigma improvement projects, the research results will broaden their relevance and address sustainability's economic, social, and ecological facets.
Caiado et al. (2018)	Review	Systematic Literature review	The suggested framework outlines fresh perspectives and methods for achieving harmony among services' concerns regarding technology, society, the economy, and the environment.
Kaswan and Rathi (2020a)	Empirical	Principal Component Analysis, Best Worst Method	The findings show that management-related, organisational, and environmental barriers are among the top three obstacles.
Kaswan et al. (2023)	Empirical	Grey relation analysis (GRA) Best Worst Method Sensitivity Analysis	The productivity-related factor has been discovered to be the most important of the other criteria. Using GRA to evaluate potential GLS initiatives in the manufacturing industry, six sustainability-related criteria were used to identify the project with the most significant potential for sustainable improvement.
Yadav and Gahlot (2022)	Empirical	DMAIC approach	Financial constraints, a lack of consumer interaction, and a need for greater awareness of Kaizen are the most significant obstacles to implementing GLSS. LCA, 5S, and Environmental value stream mapping have also been discovered to be the most frequently used GLSS tools.

III. RESEARCH METHODOLOGY

This pertains to the method or process the researcher would use when choosing objects for the sample (Kothari,2004). There are two types of sampling: probability sampling and nonprobability sampling. The present research uses non-probability sampling.

The probability sampling method is based on random sampling or chance sampling, which takes a sample at random from the population of the group of people or things you are interested in. Every individual or item in the population has an equal selection opportunity. This sampling allows researchers to obtain a representative sample and extrapolate the study's findings to the entire population. Since the researcher deliberately chooses the people or objects for the sample, nonprobability sampling is not random. Researchers also know this technique as purposeful, judgmental, or deliberate sampling. Thus, in a non-probability sampling scenario, the researcher deliberately selects specific units of the universe to form a sample, reasoning that a small mass chosen from a large one will indicate the entire. A literature analysis was conducted to determine the strategies' current status, and responses were collected from the Indian manufacturing industries. The research methodology adopted for the same is shown in Fig. 4.1.

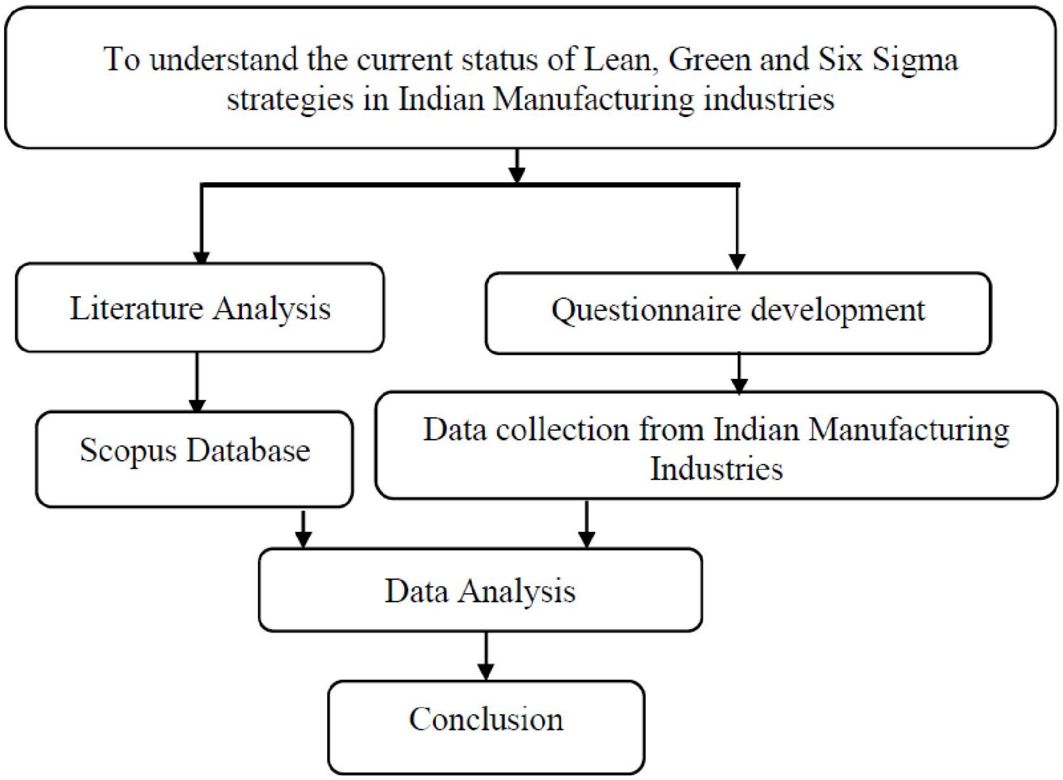

Figure 1 Research methodology

The questionnaire was shared, and responses were gathered from Indian Manufacturing industries through email correspondence and in-person visits to the manufacturing facility. The questionnaire was shared with 54 manufacturing industries. Out of that, only 14 manufacturing units were ready to provide valuable responses in the present study. Based on the responses collected from the Indian manufacturing industries about the degree of implementation of different strategies, it is seen that lean and green practices are fairly implemented, as illustrated in Fig. 4.3. The degree to which lean and green tools have been applied is evaluated on a scale from 1 to 5 which is shown in Fig. 4.4 and 4.5 respectively. Additionally, characteristics of Indian manufacturing businesses are outlined in Table 4.2.

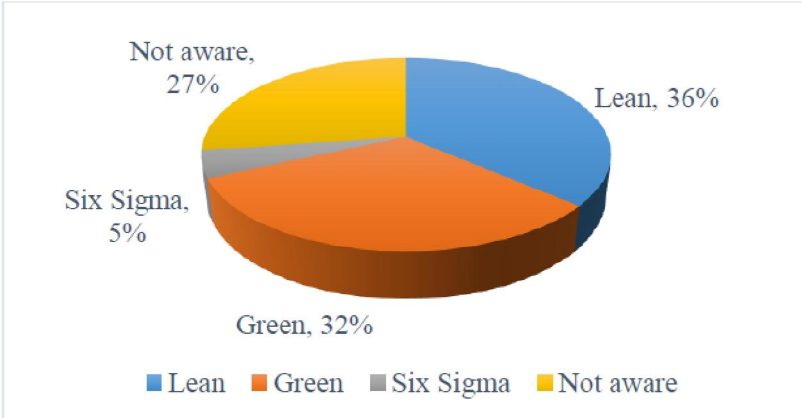

Figure. 2 Implementation status of strategies

The degree to which lean and green tools have been applied is evaluated on a scale from 1 to 5 which is shown in Fig. 3 and 4 respectively. Additionally, characteristics of Indian manufacturing businesses are outlined in Table 4.2.

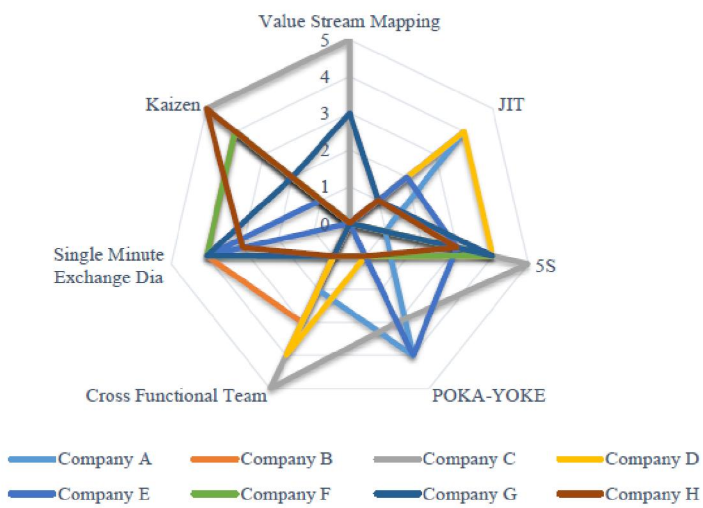

FIGURE 3 Implementation level of lean practices

The review of literature from the Scopus database reveals that a total of 171 papers have been published on the integration of Lean, Green, and Six Sigma (LG&SS) strategies, with 49 of these papers originating from India. The journey of integrated LG&SS research in India began in 2015, and since then, there has been a noticeable increase in interest, peaking in 2021 with the highest annual output of 11 articles. Among the various tools and practices within the Lean and Green methodologies, Kaizen, 5S, and 3R are particularly prominent in the manufacturing sector. Due to poor adoption of lean, green and Six Sigma strategies, first analysed the barriers to implementation of LG&SS. The next section covers the barriers that hinder integrating LG&SS in the Indian manufacturing industry. This includes the identification of barriers through a literature review and the development of a model by using the ISM technique and fuzzy MICMAC analysis to classify barriers as autonomous, driver, linkage, and dependent.

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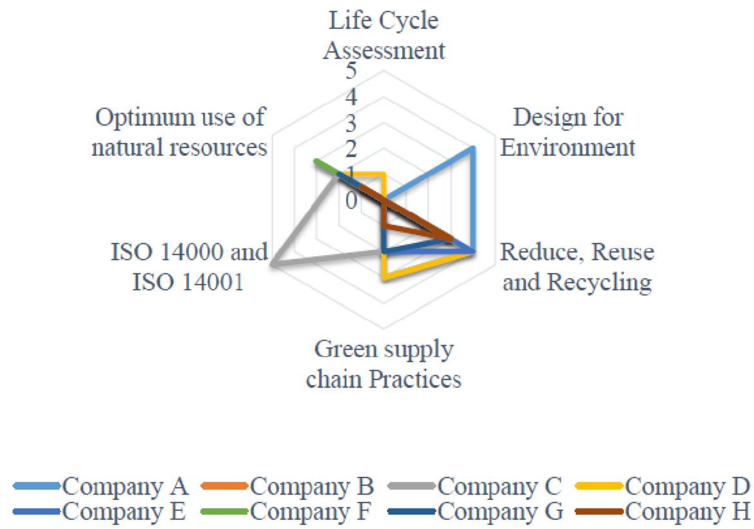

Figure 4 Implementation level of green practices

IV. RESULT ANALYSIS

The ISM approach allows for identifying the leading research variables and may also systematically help identify the contextual interrelationships among the variables involved (Warfield, 1974). A few researchers have applied the ISM approach in modelling barriers and enablers, such as it being used to understand the interrelationships between barriers and enablers (Kumar & Kumar, 2017; Kaswan & Rathi, 2019). ISM has proven to help determine the contextual connections between these barriers and classify them by comparing driving and dependents' potential towards developing a model of these barriers (Singh & Gupta, 2019). An essential benefit of the ISM approach is transforming the unclear model into a well-structured one using a systematic approach (Khaba & Bhar, 2017). The paper followed the steps of the ISM approach, as Mandal and Deshmukh (1994) discussed. The present research identifies the contextual relationship between the barriers between industrial experts and academicians. The contextual relationship between barriers (i and j) was focused, and their relationship directions were analysed. Four characters are used to represent the relationship direction among barriers (i and j) that are as follows:

V- Barrier i affects the barrier j;

I- Barrier j affects the barrier i;

X- Barriers i and j affect each other, and

O- Barrier i and j are unrelated

SSIM has been created based on the contextual relationship between the barriers. Table 2 represents the directional relationship by using the characters mentioned above.

TABLE 2 SSIM of barriers

Barrier code	B18	B17	B16	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2
B1	A	A	A	A	X	A	V	O	V	X	V	X	V	V	V	V	V
B2	O	A	A	A	V	A	A	A	X	A	V	V	V	A	X	V	
B3	O	O	O	O	O	O	A	O	A	O	V	A	O	O	A		
B4	O	O	O	O	O	O	A	O	A	O	A	O	A	O			
B5	O	A	O	O	V	O	O	O	A	A	V	A	V				
B6	O	O	O	O	O	A	A	A	A	A	V	A					
B7	A	O	O	O	O	A	V	O	V	V	V						
B8	O	O	O	O	X	A	A	A	A	A							

B9	O	O	O	O	O	A	O	V	V									
B10	O	A	O	O	O	A	V	V										
B11	O	A	0	O	O	0	O											
B12	O	O	O	O	O	A												
B13	X	A	A	A	O													
B14	A	A	A	A														
B15	O	A	X															
B16	O	A																
B17	O																	
B18																		

V. CONCLUSION

The overall effort put into the present research has resulted in mainly three deliverables: (1) Identification of critical barriers for lean, green and Six Sigma implementation in the Indian manufacturing industry; (2) Development of digraph for understanding interrelationships among LG&SS barriers; (3) Developing key managerial insights and recommendations to classify barriers into four categories. Eighteen barriers to lean, green and Six Sigma implementation in India's manufacturing industry have been found appropriate and analysed. The ISM technique is a proper approach to finding the interrelationship between the barriers of lean, green, and Six Sigma strategies in India's manufacturing industry. "Lack of cooperation and mutual trust between management and employee, "scarcity of time and work pressure", "lack of continuous improvement work culture" and "lack of cooperation from suppliers" form the topmost level of the model. "Weak legislation" is a significant barrier to LGSS implementation in the Indian manufacturing industry as it includes a base for the ISM model. Fuzzy MICMAC analysis has helped cluster these barriers into autonomous, driver, linkage and dependent barriers that will further help practitioners deal with them towards achieving their goals. Six barriers are found as drivers, whereas four are seen as linkage barriers. Six barriers are found to be dependent, and two barriers are classified as autonomous. Once barriers to LG&SS implementation have been identified and classified, it becomes crucial to pinpoint the enablers of LG&SS. The subsequent chapter delves into these enablers and elaborates on the causal relationships among them.

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