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# Confirmatory factor analysis for the implementation of Green Lean Six Sigma (GLSS) in Malaysia's wastewater treatment industry

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## ABSTRACT

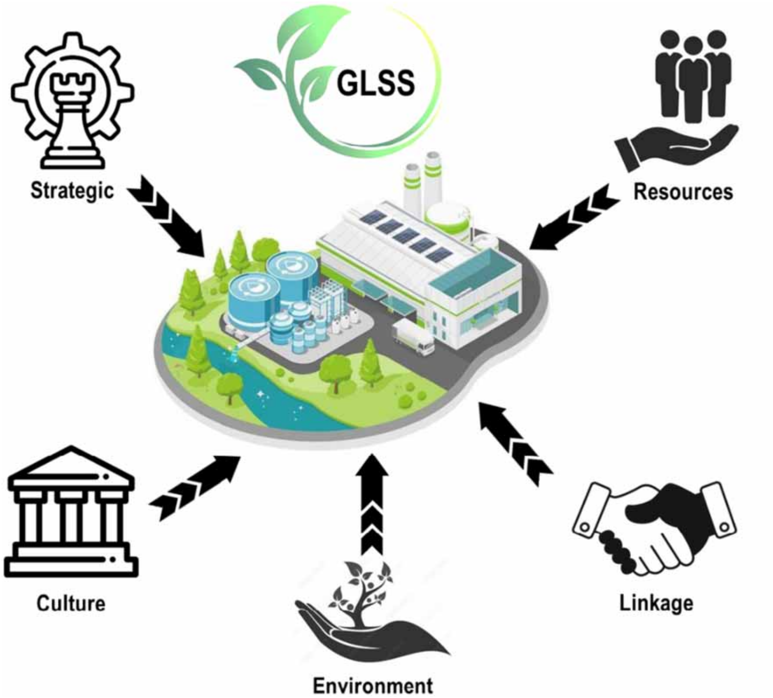
This study investigates the critical enablers influencing the implementation of Green Lean Six Sigma (GLSS) in Malaysia's wastewater treatment industry. Through an extensive literature review and insights from the industry, 30 distinct enablers were identified and categorized based on their characteristics within wastewater treatment plant (WWTP) organizations, aimed at ensuring successful GLSS execution. Structural equation modelling was employed to validate the research model, utilizing data from 296 certified professionals in Malaysia. The analysis revealed five significant enablers, indicating moderate to high levels of GLSS adoption within the industry, with the 'strategic' and 'resource' enablers emerging as particularly influential factors. Subsequent confirmatory factor analysis further affirmed the validity and reliability of these enablers. Moreover, the findings demonstrated both convergent and discriminant validity, reinforcing the efficacy of these factors in measuring GLSS implementation in Malaysian WWTPs. The study highlights the critical importance of strategic planning and resource allocation while emphasizing the need to address cultural and environmental factors for successful GLSS adoption in the industry. However, enablers based on linkages, particularly those pertaining to supplier relationships and customer satisfaction, garnered the least consensus among respondents, indicating areas necessitating further attention and improvement.

**Key words:** Critical enablers, Green manufacturing, Lean Six Sigma, Structural equation modelling, Wastewater treatment

## HIGHLIGHTS

- This study represents the first integrated CFA model combining the concepts of green manufacturing to examine the sustainability of wastewater treatment plant (WWTP) operations.
- The research underscores the novelty of its theoretical and managerial implications, prompting WWTP professionals to reconsider their current operational management strategies to facilitate improved outcomes in treated quality, nutrient recovery, and energy conservation.

## GRAPHICAL ABSTRACT




## 1. INTRODUCTION

The progression of modernization in manufacturing, driven by the increasing global recognition of environmental risks and the pursuit of enhanced efficiency, has evolved from traditional substitution focus to lean manufacturing, which minimizes waste, and further advanced to green manufacturing guided by the principles of reduce, reuse, and recycle (3Rs) (Sagnak & Kazancoglu, 2016). Enterprises have proactively developed cleaner manufacturing processes and environmentally friendly products. However, numerous industrial activities significantly impact the environment and society assigned to excessive resource consumption, generation of hazardous wastes, and emissions (Parmar & Desai, 2020).

Wastewater, encompassing various types such as sewage, domestic, storm run-off, agricultural, and industrial wastewater (Ishak *et al.*, 2022a), constitutes a notable component of industrial waste. According to the United Nations, approximately 1.6 billion people face economic water shortage, and two-thirds of the world's population experience water scarcity for at least 1 month per year (Christou *et al.*, 2024). This scarcity issue is exacerbated by the fact that around 97% of Malaysia's total raw water supply is derived from freshwater bodies, including lakes, rivers, and tributaries (Kozaki *et al.*, 2016). The problem of water pollution, which has historical roots in urbanization and modernization, continues to escalate in severity (Ismail *et al.*, 2020). Furthermore, industrial effluents pose significant harm to ecosystems. When poorly treated or directly released into sewers, they pollute groundwater and water bodies, adversely affecting animals and aquatic life. Inadequate treatment also leads to air and land pollution, which negatively impacts soil quality. Disposal of industrial wastewater poses risks to crops and potentially disrupts the food chain, contributing to the spread of waterborne diseases (Von Sperling *et al.*, 2020).

Wastewater treatment plants (WWTPs) face multifaceted challenges, including influent fluctuations, reactor dynamics, pollutant origins, process variability, mechanical anomalies, and human proficiency. Equipment malfunction, including damage, breakdowns, and unforeseen downtime, poses a substantial concern in environmental control, disrupting treatment processes and compromising the quality of treated wastewater (Ishak *et al*., 2022b). Remedial techniques have emerged to identify operational shortcomings and rectify instability and inadequacies in treatment methodologies. Scholars have developed approaches combining green and lean concepts (Siegel *et al*., 2019) to minimize not only waste production but also 'green waste' (Caiado *et al*., 2018), defined by the United States Environmental Protection Agency (US EPA) as avoidable resource consumption or substance release detrimental to humans and the environment (United States Environmental Protection Agency, 2007). Optimizing the usage of energy, water, chemicals, materials, or transportation can profoundly impact ecosystems.

Recognizing the limitations of green and lean as independent strategies and as an integrated paradigm, Green Lean Six Sigma (GLSS) emerges as a pioneering environmental developmental agenda, transcending these constraints and enhancing the effectiveness of green lean initiatives (Shokri & Li, 2020). This integration draws strength not only from the intrinsic cohesion of lean principles and tools common in both approaches but also from their ostensibly shared attributes (Rahman & James, 2019). Although numerous studies have showcased the effectiveness of this integration, further cutting-edge research, particularly empirical inquiries offering structured guidelines for applying GLSS across diverse domains, is imperative (Gholami *et al*., 2021). Precisely defining this concept necessitates the systematic consolidation of available knowledge regarding this GLSS initiative.

Despite its recognized potential in the manufacturing industry, practitioners exhibit caution in GLSS adoption (Farrukh *et al*., 2021). Consequently, there is a research imperative to scrutinize the factors facilitating GLSS implementation in WWTPs. Notably, no prior studies have explicitly and systematically addressed a comprehensive model of GLSS in WWTP operations, indicating a need for a unified model. Critical tasks involve organizing existing GLSS insights and identifying impediments, particularly within Malaysian WWTPs where specific GLSS enablers remain unexplored. This study aims to augment current knowledge and expedite GLSS implementation by (1) delineating key factors enabling GLSS implementation, (2) constructing a structured framework for GLSS integration in the Malaysian WWTP sector, and (3) empirically investigating the GLSS enabler's model in WWTP operations using structural equation modelling (SEM).

## 2. LITERATURE REVIEW

In the literature, enablers are recognized as key factors that significantly influence the alignment of quality management with organizational goals and performance (Yadav & Desai, 2017). Various researchers have explored enablers within the realm of GLSS. For instance, Kumar *et al*. (2015) conducted a study identifying the 44 GLSS enablers that impact the sustainability performance of Indian enterprises. Singh *et al*. (2021) employed a hybrid Best-Worst method (BWM), analytic hierarchy process (AHP), and analytic network process (ANP) approach to categorize five types of GLSS enablers, including strategic, environmental, cultural, resource, and linkage-based enablers.

Strategic enablers, propelled by top management's commitment, serve as catalysts for GLSS by promoting innovation (Kaswan & Rathi, 2020a), resource allocation, and employee motivation (Kaswan & Rathi, 2019). Their adept decision-making skills contribute to sustainability and organizational improvements (Hariyani & Mishra, 2022; Shokri *et al*., 2022). Additionally, effective project leadership, encompassing diverse roles, fosters transparency, cooperation, and alignment with business objectives, leading to significant outcomes (Ershadi *et al*., 2021; Mishra, 2022). Furthermore, integrating rewards for employees encourages heightened engagement with human resources, enhancing eco-friendly results, thus reinforcing fairness and loyalty (Parmar & Desai, 2020; Letchumanan *et al*., 2022).

Organizational readiness necessitates competent individuals and supportive structures (Kaswan & Rathi, 2020b), which are important for sustainable GLSS adoption (Letchumanan *et al*., 2022; Mishra, 2022). Moreover, robust performance measurement and reliable results tracking are crucial (Pandey *et al*., 2018), especially in dynamic WWTP operations, guiding decision-making and error-proofing through feedback mechanisms (Singh *et al*., 2021). Additionally, a resilient data collection system facilitates structured information retrieval, enabling comparisons across WWTP stages and the supply chain. Monitoring and controlling using information tools are central for effective management in GLSS contexts (Hariyani & Mishra, 2022).

Transitioning to green practices in manufacturing (Farrukh *et al*., 2021), including WWTP operations, facilitates the reduction of energy use, $CO_2$ emissions, and waste generation, thereby positively impacting environmental performance (Abdul-Rashid *et al*., 2017; Kaswan & Rathi, 2019; Farrukh *et al*., 2022). Environmental-based enablers, such as emphasizing biodegradable packaging and supplier adherence (Dieste *et al*., 2019), for instance, utilizing materials like biodegradable options and lightweight, flexible packaging, help minimize costs and environmental emissions (Farrukh *et al*., 2023a; Rathi *et al*., 2023). In many cases, environmental initiatives rely on government regulations to support GLSS through incentives like subsidies, influencing top management, and enhancing organizational capabilities (Hariyani & Mishra, 2022).

Additionally, eco-design prioritizes minimizing environmental footprints (Parmar & Desai, 2020), aligning with WWTP goals (Ishak *et al*., 2022b), which not only focus on treating wastewater to acceptable standards but also optimize energy recovery and nutrient recovery sources. Furthermore, the impact of logistics and transportation on emissions underscores the importance of green methods (Pandey *et al*., 2018). Similarly, WWTP practices optimize chemical use and effluent transport, promoting sustainability (Rimantho & Nugraha, 2020). Moreover, the environmental management system (EMS) integrates various environmental activities (Shokri *et al*., 2022), enhancing facility sustainability (Singh & Rathi, 2022, 2023). Additionally, stakeholder pressure emphasizes demands for eco-conscious practices (Gandhi *et al*., 2018; Parmar & Desai, 2019), driven by regulations and consumer preferences for green initiatives (Nagadi, 2022) and sustainable performance (Yadav *et al*., 2023a, b).

In culture-based enablers, team selection holds paramount importance (Kumar *et al*., 2015), leveraging diverse skills and experiences as valuable assets (Singh *et al*., 2021). For example, talented WWTP employees enhance treatment efficiency (Letchumanan *et al*., 2022; Mishra, 2022), emphasizing unified effort and effective communication channels (Pandey *et al*., 2018). Similarly, GLSS emphasizes teamwork for sustainable improvements (Kaswan & Rathi, 2020a), supported by effective communication (Hussain, *et al*., 2023; Hariyani & Mishra, 2024) and inter-departmental exchanges (Singh *et al*., 2021; Hariyani *et al*., 2023; Hussain *et al*., 2023).

Moreover, efficient scheduling (Yadav *et al*., 2021; Shokri *et al*., 2022) aids environmental sustainability (Letchumanan *et al*., 2022). Similarly, motivating employees (Singh *et al*., 2021; Mishra, 2022) and cross-departmental sharing enhances efficiency (Hussain *et al*., 2023). Likewise, sharing success stories facilitates learning (Mishra, 2022), emphasizing factors such as management commitment and training (Singh *et al*., 2021). Ultimately, GLSS culture values sustainability (Gandhi *et al*., 2018), ethics (Kaswan & Rathi, 2019), and profitability (Kaswan & Rathi, 2020a; Hariyani & Mishra, 2023; Rathi *et al*., 2023). Therefore, cooperative WWTP environments focus on quality, efficiency, and participative cultures (Letchumanan *et al*., 2022; Mishra, 2022) for successful GLSS implementation (Hussain *et al*., 2023).

The GLSS methodology, integrating Lean Six Sigma (LSS; Yadav *et al*., 2021) and flow cost accounting, addresses inefficiencies (Kaswan & Rathi, 2019). Emphasis is placed on understanding for successful adoption (Hussain *et al*., 2023). Project selection aligns with sustainability (Parmar & Desai, 2019), utilizing Lean tools such as fishbone diagrams for prioritizing improvements and resource allocation to enhance continuous improvement projects in organizations (Letchumanan *et al.*, 2022; Hussain *et al.*, 2023). Mastery of project selection and prioritization skills (Singh *et al.*, 2021; Rathi *et al.*, 2023), along with effective training, is crucial (Hariyani & Mishra, 2024) for GLSS success (Mishra, 2022).

Careful financial planning (Hussain *et al.*, 2023) ensures effective resource allocation for technology upgrading (Kumar *et al.*, 2015; Singh *et al.*, 2021), particularly in WWTP operations, which require capacity and efficiency commensurate with process enlargement. Periodical staff training improves skill sets, employability, team spirit, and organizational cohesiveness (Shokri *et al.*, 2022). Continual assessment of financial benefits (Pandey *et al.*, 2018; Yadav *et al.*, 2021) and early involvement of finance departments are essential (Letchumanan *et al.*, 2022; Shokri *et al.*, 2022; Hussain *et al.*, 2023) for effective resource management. In WWTP operations, selecting eco-friendly polymers, exemplified by involving financial perspectives for cost-effective measures, helps reduce long-term treatment expenses and environmental impact (Singh *et al.*, 2021; Mohan *et al.*, 2022).

Supplier engagement in GLSS promotes innovation and quality improvement (Kaswan & Rathi, 2020b; Parmar & Desai, 2020). Ensuring reliable suppliers is crucial for the timely delivery of chemicals, nutrient additives, and mechanical equipment, which are vital for WWTP operations' performance and waste management (Digalwar *et al.*, 2020; Singh *et al.*, 2021), including bio-sludge and solid waste disposal. Moreover, customer satisfaction in WWTP operations depends on adaptable processes, legal compliance, cost control, and pollution prevention (Kaswan & Rathi, 2020b). Accurate predictions and digital advancements enhance customer satisfaction and engagement (Singh *et al.*, 2021). Customer involvement is integral to GLSS success (Pandey *et al.*, 2018), prioritizing satisfaction through feedback and database utilization (Ershadi *et al.*, 2021).

Meeting customer demand entails maintaining stable treated wastewater quality and cost-effective plant operations (Singh *et al.*, 2021). Strong customer–supplier relationships (Pandey *et al.*, 2018; Letchumanan *et al.*, 2022) focusing on sustainability, optimizing outcomes, and minimizing waste (Hariyani & Mishra, 2024) contribute to efficient treatment processes. Integrating GLSS into strategy enhances sustainability (Kaswan & Rathi, 2020b; Hussain *et al.*, 2023), fostering staff responsibility (Farrukh *et al.*, 2019) and collaboration (Farrukh *et al.*, 2021) in high-risk operations such as WWTP.

In conclusion, this literature review explores essential GLSS enablers for sustainable operations, aiming to underscore the importance of holistic assessments of these enablers to optimize their impact on operational sustainability and to further enhance Malaysia's wastewater treatment practices. Understanding the interplay among these enablers will facilitate the development of improved strategies and implementation methodologies for sustainable wastewater management.

## 3. METHODOLOGY

This study constitutes exploratory research, focusing on an unexplored area within Malaysian WWTPs. It adopts a descriptive and analytical approach towards its exploratory aim, comprising two distinct phases. The first phase entails a comprehensive review of existing literature on GLSS enablers. Following this, an analytical method is formulated to conclude the research process. These steps are further elaborated upon in the subsequent sections.

To begin, following Yadav *et al.* (2023a, b) scholarly papers were gathered from reputable databases including Elsevier, Springer, Science Direct, Taylor & Francis, Emerald, Sage, and among others. A comprehensive literature review and on-site visits to actual WWTPs enabled the compilation of a list of key factors that impact the implementation of GLSS in Malaysian WWTP scenarios. Articles focusing on enablers, drivers, and critical success factors (CSFs) related to GLSS were meticulously examined, both theoretically and empirically, to inform this compilation.

Next, in the classification of GLSS enablers, experts' insights and exploratory factor analysis (EFA) have been utilized. EFA serves to gauge the identified variables and unveil the underlying relationships among them. This method yields two interconnected outcomes: data summarization and reduction. Through data summarization, EFA identifies core dimensions that succinctly encapsulate the data, condensing numerous individual variables into a smaller set of concepts. Data reduction builds on this by assigning a numerical value (factor score) to each dimension (factor), replacing the original values. Many researchers find EFA valuable for uncovering patterns among variables or as a means of streamlining data. This analytical approach encompasses three primary components, elaborated upon in the following sections.

The EFA design focused on two critical queries: identifying key GLSS enablers and determining an optimal sample size. A comprehensive literature review and collaboration with certified LSS Belts, National Registration of Certified Environmental Professional experts in WWTP operations, and a GLSS academician led to refining 30 enablers. Hair *et al.* (2019) recommends at least 50 observations for EFA, while Habidin & Yusof (2013) used 161 observations to identify the LSS CSFs model in the Malaysian automotive sector. Employing non-probabilistic convenience sampling, 296 responses were collected from local WWTP professionals between February and May 2023. A five-point Likert scale measured perceptions of agreement (strongly disagree – 1 to strongly agree – 5) regarding GLSS enabler importance, validated by another five WWTP experts. A pilot study ensured questionnaire clarity and relevance. Data collection targeted diverse viewpoints from technicians, engineers, executives, and managers involved in various aspects of WWTP in industrial operations. Subsequent analysis choices, like factor extraction methods and matrices, will critically shape the understanding of the identified enablers' underlying structure. These decisions are crucial for interpreting the study's outcomes effectively.

Again, Hair *et al.* (2019) advocates using principal component analysis (PCA) with varimax rotation due to its ability to consider total variance and highlight factors with less unique variance. This method maximizes variance in factor loadings, simplifies fundamental structures, and aids in factor division (Hashemi *et al.*, 2022). Employing IBM SPSS version 27, this study used Bartlett's test of sphericity (BTS) and Kaiser–Meyer–Olkin (KMO) measure to assess data suitability. Acceptable EFA standards include BTS at 0.05 significance and KMO between 0 and 1, with 0.5 as minimal adequacy (de Freitas *et al.*, 2017). Criteria for determining factor numbers include variance contribution (>20%), eigenvalues (>1), and the Scree test (Hair *et al.*, 2019), while Letchumanan *et al.* (2021) suggest considering factor loadings >0.5. Internal consistency, evaluated by Cronbach's $\alpha$ (>0.6), ensures reliability in the exploratory survey.

Finally, SEM, increasingly popular in operations management empirical studies (Habidin & Yusof, 2013), combines regression and factor analysis to explore relationships between observed and latent variables. It comprises two stages: EFA, exploring links between observed and unobserved variables, and confirmatory factor analysis (CFA), confirming and validating models as explained previously by EFA. While CFA, conducted in Analysis of Moment Structure (AMOS) version 24, validates the measured and structural models. This method enables a comprehensive evaluation of complex relationships between variables in this study.

## 4. RESULTS AND DISCUSSION

The study assessed the reliability and validity of GLSS enablers through an EFA. Initially, 30 enablers were identified from an extensive literature review and industrial visit. These enablers were distinct in their characteristics and application within WWTP organizations to ensure the successful execution of GLSS. They were categorized based on their traits, employing both fundamental and statistical methods. Building on prior work by Singh *et al.* (2021), EFA was conducted to unveil the structure of GLSS using these 30 enablers, as outlined in Table 1.

PCA was employed to evaluate responses gathered from 296 experts working in various Malaysian WWTPs. This insight from experts is crucial as it provides decision-makers with a comprehensive understanding of a significant stakeholder group. The analysis revealed a high overall reliability coefficient ($\alpha$) of 0.969, which is considered suitable (Hair *et al.*, 2019). Moreover, the KMO measure surpassed the threshold of 0.7 at 0.968,

**Table 1** | Total variance, eigenvalues, and reliability coefficients of the structured factors.

| Total variance explained[a] | | Factor[b,d] 1. Stra | 2. Env | 3. Cul | 4. Res | 5. Lnk |
|---|---|---|---|---|---|---|
| Initial eigenvalues | Total | 15.998 | 1.606 | 1.456 | 1.092 | 1.047 |
| | Variance (%) | 53.325 | 5.354 | 4.855 | 3.641 | 3.490 |
| | Cumulative (%) | 53.325 | 58.679 | 63.534 | 67.175 | 70.666 |
| Rotation sums of squared loadings | Total | 4.988 | 4.430 | 4.409 | 4.010 | 3.363 |
| | Variance (%) | 16.628 | 14.766 | 14.695 | 13.365 | 11.212 |
| | Cumulative (%) | 16.628 | 31.393 | 46.089 | 59.454 | 70.666 |
| Cronbach's alpha ($\alpha$)[c] | | 0.924 | 0.939 | 0.895 | 0.866 | 0.924 |

[a]Extraction method: PCA.
[b]Rotation has been performed by the Varimax method in eight iterations.
[c]Overall reliability = 0.969.
[d]KMO = 0.968. BTS is significant at $p < 0.001$.

indicating the adequacy of the data for PCA. Similarly, the BTS was significant ($p < 0.001$), affirming sufficient correlation among the items to proceed with the analysis.

The EFA identified five factors among the 30 GLSS items, explaining 70.666% of the total variance. None of the enabler items were suggested for exclusion. The determination of the total factor number for extraction was based on the widely used criteria, including the proportion of contribution to total variance, eigenvalues, and the Scree plot. The Scree plot indicated a clear drop and then stabilization at five factors, depicted in Figure 1. Additionally, the reliability measure of GLSS using Cronbach's $\alpha$ ranged from 0.866 to 0.939, where values equal to or greater than 0.60 are indicative of reliability (Abu *et al.*, 2019). Each factor exhibited a Cronbach's $\alpha$ value above 0.70, all factors were deemed reliable for the research. Consequently, all 30 initial enablers were retained as they displayed factor loadings >0.5, as detailed in Table 2.

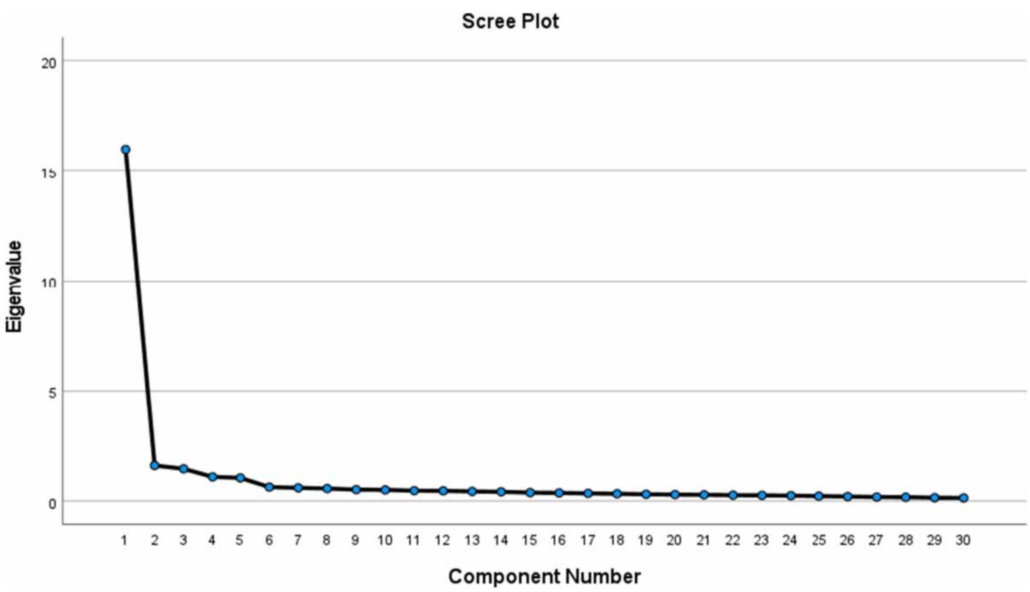



**Fig. 1** | Scree plot test.

**Table 2** | EFA structure of GLSS enablers.

| Enablers | Code | Comm[a] | Factors 1 | 2 | 3 | 4 | 5 | References |
|---|---|---|---|---|---|---|---|---|
| Top management commitment | EStra1 | 0.694 | 0.733 | | | | | Kumar *et al.* (2015), Kaswan & Rathi (2019, 2020b), Singh *et al.* (2021), Shokri *et al.* (2022), and Hariyani & Mishra (2022) |
| Effective project leadership | EStra2 | 0.778 | 0.717 | | | | | Kumar *et al.* (2015), Ershadi *et al.* (2021), Singh *et al.* (2021), Hariyani & Mishra (2022), and Mishra (2022) |
| Rewards and incentives to employees | EStra3 | 0.698 | 0.690 | | | | | Kumar *et al.* (2015), Parmar & Desai (2020), Singh *et al.* (2021), Ershadi *et al.* (2021), and Letchumanan *et al.* (2022) |
| Supportive organizational infrastructure | EStra4 | 0.755 | 0.675 | | | | | Kumar *et al.* (2015), Kaswan & Rathi (2020a), Mishra (2022), and Letchumanan *et al.* (2022) |
| Performance measurement system | EStra5 | 0.763 | 0.719 | | | | | Kumar *et al.* (2015), Pandey *et al.* (2018), Singh *et al.* (2021), Ershadi *et al.* (2021), and Letchumanan *et al.* (2022) |
| Consistent and accurate data collection | EStra6 | 0.736 | 0.668 | | | | | Kumar *et al.* (2015), Ershadi *et al.* (2021), Hariyani & Mishra (2022), Letchumanan *et al.* (2022), and Hariyani & Mishra (2024) |
| Carbon reduction initiatives | EEnv1 | 0.716 | | 0.592 | | | | Abdul-Rashid *et al.* (2017), Kaswan & Rathi (2019), Farrukh *et al.* (2021, 2022), and Singh *et al.* (2021) |
| Eco-packaging | EEnv2 | 0.745 | | 0.726 | | | | Dieste *et al.* (2019), Farrukh *et al.* (2019, 2023a, b), and Rathi *et al.* (2023) |
| Incentives for eco-products | EEnv3 | 0.662 | | 0.637 | | | | Kumar *et al.* (2015), Abdul-Rashid *et al.* (2017), Singh *et al.* (2021), and Farrukh *et al.* (2022) |
| Eco-design practices | EEnv4 | 0.790 | | 0.760 | | | | Kumar *et al.* (2015), Farrukh *et al.* (2019), Singh *et al.* (2021), and Letchumanan *et al.* (2022) |
| Eco-transportation practices | EEnv5 | 0.817 | | 0.791 | | | | Kumar *et al.* (2015), Pandey *et al.* (2018), Singh *et al.* (2021), and Letchumanan *et al.* (2022) |
| Green operational practices | EEnv6 | 0.752 | | 0.675 | | | | Singh *et al.* (2021), Shokri *et al.* (2022), and Singh & Rathi (2023) |
| Market demand for eco-products | EEnv7 | 0.720 | | 0.682 | | | | Kumar *et al.* (2015), Gandhi *et al.* (2018), Parmar & Desai (2019), Nagadi (2022), and Yadav *et al.* (2023a, b) |
| Select and retention of employees | ECul1 | 0.621 | | | 0.636 | | | Kumar *et al.* (2015), Singh *et al.* (2021), Mishra (2022), and Letchumanan *et al.* (2022) |
| Teamwork | ECul2 | 0.643 | | | 0.659 | | | Pandey *et al.* (2018), Kaswan & Rathi (2019, 2020a), Singh *et al.* (2021), |

(*Continued.*)

**Table 2** | Continued

| Enablers | Code | Comm[a] | Factors 1 | 2 | 3 | 4 | 5 | References |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Hariyani & Mishra, (2024), and Hussain *et al.* (2023) |
| Effective communication | ECul3 | 0.639 | | | 0.629 | | | Kumar *et al.* (2015), Singh *et al.* (2021), Letchumanan *et al.* (2022), Hariyani & Mishra, (2024), and Hussain *et al.* (2023) |
| Effective scheduling | ECul4 | 0.631 | | | 0.602 | | | Kumar *et al.* (2015), Pandey *et al.* (2018), Gandhi *et al.* (2018), Yadav *et al.* (2021), and Shokri *et al.* (2022) |
| Empowering employees | ECul5 | 0.603 | | | 0.624 | | | Kumar *et al.* (2015), Pandey *et al.* (2018), Singh *et al.* (2021), Shokri *et al.* (2022), and Mishra (2022) |
| Sharing success stories | ECul6 | 0.672 | | | 0.709 | | | Yadav & Desai (2017), Singh *et al.* (2021), Mishra (2022), and Hussain *et al.* (2023) |
| Organizational culture and ethic | ECul7 | 0.615 | | | 0.641 | | | Kumar *et al.* (2015), Gandhi *et al.* (2018), Kaswan & Rathi (2019), Mishra (2022), Letchumanan *et al.* (2022), and Hariyani & Mishra (2023) |
| Understand GLSS methodology | ERes1 | 0.724 | | | | 0.705 | | Kumar *et al.* (2015), Kaswan & Rathi (2019), Singh *et al.* (2021), Yadav *et al.* (2021), and Hussain *et al.* (2023) |
| Project selection and prioritization | ERes2 | 0.611 | | | | 0.597 | | Kumar *et al.* (2015), Parmar & Desai (2019), Singh *et al.* (2021), Letchumanan *et al.* (2022), and Hussain *et al.* (2023) |
| Awareness program and training | ERes3 | 0.659 | | | | 0.650 | | Kumar *et al.* (2015), Singh *et al.* (2021), Mishra (2022), Hariyani & Mishra, (2024), Rathi *et al.* (2023), and Hussain *et al.* (2023) |
| Effective resource allocation | ERes4 | 0.653 | | | | 0.679 | | Pandey *et al.* (2018), Singh *et al.* (2021), Yadav *et al.* (2021), Shokri *et al.* (2022), Letchumanan *et al.* (2022), and Hussain *et al.* (2023) |
| Sharing financial benefits | ERes5 | 0.645 | | | | 0.632 | | Singh *et al.* (2021) and Mohan *et al.* (2022) |
| Supplier management | ELnk1 | 0.762 | | | | | 0.676 | Kumar *et al.* (2015), Parmar & Desai (2020), Kaswan & Rathi (2020b), Digalwar *et al.* (2020), and Singh *et al.* (2021) |
| Customer satisfaction and delight | ELnk2 | 0.786 | | | | | 0.783 | Kumar *et al.* (2015), Kaswan & Rathi (2020b), Farrukh *et al.* (2020), and Singh *et al.* (2021) |
| Customer demand | ELnk3 | 0.735 | | | | | 0.711 | Kumar *et al.* (2015), Pandey *et al.* (2018), Parmar & Desai (2020), Singh *et al.* (2021), and Ershadi *et al.* (2021) |

(*Continued.*)

**Table 2** | Continued

| Enablers | Code | Comm[a] | Factors 1 | 2 | 3 | 4 | 5 | References |
|---|---|---|---|---|---|---|---|---|
| Link of GLSS with customer/supplier | ELnk4 | 0.787 | | | | | 0.781 | Kumar *et al.* (2015), Pandey *et al.* (2018), Singh *et al.* (2021), and Hariyani & Mishra (2024) |
| Integrating GLSS in core business | ELnk5 | 0.787 | | | | | 0.752 | Kumar *et al.* (2015), Farrukh *et al.* (2019, 2021), Kaswan & Rathi (2020b), Hariyani & Mishra (2024), and Hussain *et al.* (2023) |

[a]Communality.

**Table 3** | CFA model fit results.

| Factor | $\chi^2$ | df | $\chi^2$/df | *p*-value | GFI | NFI | TLI | CFI | RMSEA | SRMR |
|---|---|---|---|---|---|---|---|---|---|---|
| GLSS_En | 541.71 | 391 | 1.385 | 0.001 | 0.895 | 0.925 | 0.975 | 0.978 | 0.036 | 0.033 |

*Note*: $\chi^2$, Chi-square; df, degree of freedom.

The following analysis involved testing the measurement model for GLSS enablers using CFA. In Table 3, the GLSS construct underwent validation via the maximum likelihood method with multiple factors. The results of the CFA showcased an exceptionally parsimonious model fit, where a $\chi^2$/df value below 3.0 signifies a good fit. Additionally, the incremental fit criteria, including goodness fit index (GFI), normed fit index (NFI), Tucker-Lewis index (TLI), and comparative fit index (CFI), close to or above 0.9, indicated a good fit. The absolute model fit, determined by a significant chi-square ($\chi^2$) value ($p < 0.001$), Root Mean Square Error of Approximation (RMSEA) = 0.036, and Standardized Root Mean Square Residual (SRMR) = 0.033, all falling below 0.08, further supported a good fit. The $R^2$ values for each indicator ranged between 0.68 and 0.82, as visually depicted in Figure 2. These results imply that these five constructs effectively measure GLSS enablers for implementation in the Malaysian WWTP sector.

Furthermore, construct validity was evaluated through assessments of convergent and discriminant validity. Convergent validity ensures consistent measurement outcomes across various variables and methods (O'Leary-Kelly & Vokurka, 1998). It was confirmed by examining composite reliability (CR) and average variance extracted (AVE) values. CR > 0.6, CR > AVE, and AVE > 0.5 criteria were met by all factors in the model (Hundleby & Nunnally, 1968; Table 4), affirming convergent validity. Discriminant validity was assessed using the Heterotrait-Monotrait (HTMT) approach, which compares inter-construct correlations (heterotrait) to intra-construct correlations (monotrait). HTMT values ranging from 0.674 to 0.815, all below the 0.9 threshold, indicated satisfactory discriminant validity (Henseler *et al.*, 2015). This conclusion was further supported by factor loadings, AVE, and cross-loadings from previous tables (Table 2), strengthening the evidence for discriminant validity.

Table 4 outlines the results of GLSS enablers in the Malaysian WWTP sector, presenting various means reflecting respondent perceptions of agreement. The overall mean for each factor was computed to gauge the perceived level of importance of GLSS enablers. These mean values range from 4.310 to 3.949, signifying a good level of agreement on the importance of GLSS enablers. The two highest-rated enablers are Strategic (4.310) and Resource (4.289), followed by Culture (4.269) and Environment (4.051). Conversely, Linkage (3.949) is perceived as the GLSS enabler with the least agreement among respondents.

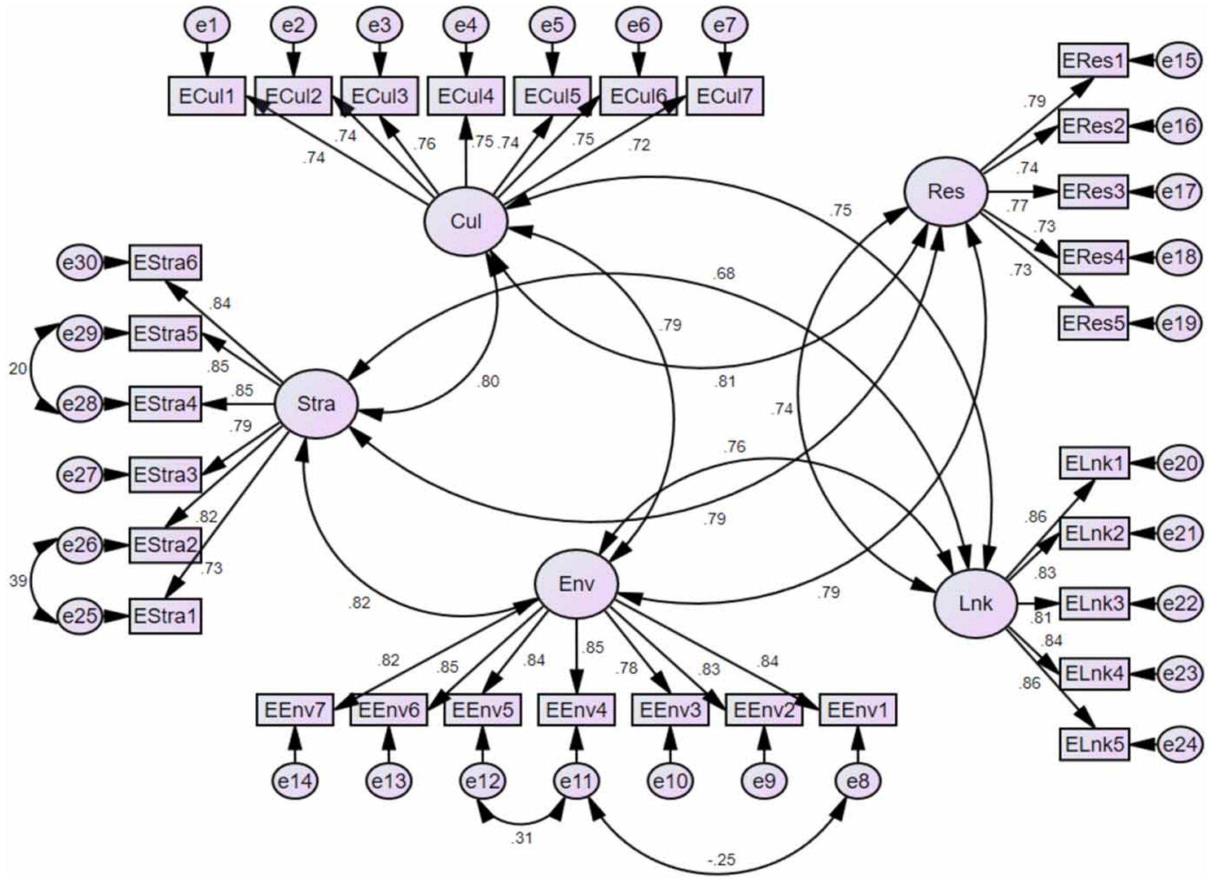



**Fig. 2** | CFA diagram for GLSS enabler's model.

Interestingly, the ranking of the top three enablers identified in this study aligns with the analytic hierarchy process (AHP) ranking in Pandey *et al.*'s (2018) research. However, a contrast emerges in this study, as the linkage-based enablers are considered the least significant, with Elnk5, Elnk2, and Elnk4 hitting the lowest mean values. This finding contradicts the outcomes of studies by Kaswan & Rathi (2019), and Rathi *et al.* (2023), where the Interpretive Structural Modeling (ISM)-Matrice d'Impacts Croisés Multiplication Appliquée à un Classement (MICMAC) model and BWM analysis highlighted the integration of GLSS in core business (Elnk5) as among the top enablers in their research.

Respondents emphasize the critical need for a strategic approach to sustainable WWTP operations. Key components include top management commitment (EStra1), effective project leadership (EStra2), and precise data collection (EStra6) within Malaysian contexts. Active support and resource provision by management are important for successful implementation (Kaswan & Rathi, 2019). According to Pandey *et al.* (2018), this strategy enhances profits by streamlining operations. Top management must ensure compliance with current pollution laws, develop plans for future regulations, and integrate technological advancements (Gandhi *et al.*, 2018). Their commitment significantly influences sustainable practices such as utilizing alternative energy and waste reduction (Kaswan & Rathi, 2020a). Consistent effective leadership is crucial in implementing manufacturing

**Table 4** | Average GLSS enabler's importance rating and CFA results.

| Factors | Mean | SD | Average mean | Average SD | Rank | Standard estimates | CR | AVE |
|---|---|---|---|---|---|---|---|---|
| *Strategic (Stra)* | | | 4.310 | 0.651 | 1 | | 0.921 | 0.660 |
| EStra1 | 4.476 | 0.627 | | | | 0.727 | | |
| EStra2 | 4.348 | 0.687 | | | | 0.819 | | |
| EStra3 | 4.233 | 0.696 | | | | 0.786 | | |
| EStra4 | 4.236 | 0.631 | | | | 0.849 | | |
| EStra5 | 4.230 | 0.623 | | | | 0.850 | | |
| EStra6 | 4.334 | 0.643 | | | | 0.836 | | |
| *Environment (Env)* | | | 4.051 | 0.705 | 4 | | 0.940 | 0.689 |
| EEnv1 | 4.101 | 0.720 | | | | 0.840 | | |
| EEnv2 | 3.973 | 0.722 | | | | 0.828 | | |
| EEnv3 | 4.101 | 0.739 | | | | 0.783 | | |
| EEnv4 | 4.044 | 0.700 | | | | 0.848 | | |
| EEnv5 | 3.946 | 0.720 | | | | 0.844 | | |
| EEnv6 | 4.105 | 0.658 | | | | 0.846 | | |
| EEnv7 | 4.088 | 0.673 | | | | 0.821 | | |
| *Culture (Cul)* | | | 4.269 | 0.577 | 3 | | 0.896 | 0.552 |
| ECul1 | 4.301 | 0.553 | | | | 0.742 | | |
| ECul2 | 4.682 | 0.508 | | | | 0.735 | | |
| ECul3 | 4.402 | 0.591 | | | | 0.757 | | |
| ECul4 | 4.135 | 0.612 | | | | 0.753 | | |
| ECul5 | 4.068 | 0.554 | | | | 0.743 | | |
| ECul6 | 4.037 | 0.590 | | | | 0.752 | | |
| ECul7 | 4.257 | 0.628 | | | | 0.716 | | |
| *Resource (Res)* | | | 4.289 | 0.582 | 2 | | 0.868 | 0.568 |
| ERes1 | 4.264 | 0.662 | | | | 0.793 | | |
| ERes2 | 4.128 | 0.568 | | | | 0.739 | | |
| ERes3 | 4.372 | 0.556 | | | | 0.770 | | |
| ERes4 | 4.527 | 0.552 | | | | 0.730 | | |
| ERes5 | 4.152 | 0.571 | | | | 0.735 | | |
| *Linkage (Lnk)* | | | 3.949 | 0.732 | 5 | | 0.924 | 0.708 |
| ELnk1 | 4.074 | 0.695 | | | | 0.857 | | |
| ELnk2 | 3.841 | 0.749 | | | | 0.834 | | |
| ELnk3 | 4.172 | 0.709 | | | | 0.814 | | |
| ELnk4 | 3.760 | 0.764 | | | | 0.840 | | |
| ELnk5 | 3.895 | 0.745 | | | | 0.863 | | |

philosophies across the organization. Accurate data collection and assessment of Lean and Green waste are crucial for thorough system analysis (Kaswan & Rathi, 2020a), assessing eco-efficiency using specific tools (Farrukh *et al.*, 2021).

The key facilitators for successful GLSS implementation revolve around essential resources, playing the second most crucial role in the sustainable process. This includes securing resource allocation (ERes4) like funding (Kumar *et al.*, 2015; Hussain *et al.*, 2023), providing necessary awareness training (ERes3) for employee skills (Singh *et al.*, 2021), and external support, such as consultant expertise (Pandey *et al.*, 2018). Thoughtful financial planning by management ensures adequate allocation of resources to meet project goals (Yadav *et al.*, 2021). This planning involves initial investments in technology, estimating tools, and staff training, emphasizing the efficient use of finances for comprehensive GLSS adoption (Letchumanan *et al.*, 2022; Shokri *et al.*, 2022). Mastery through understanding and practical application of GLSS methodology (ERes1) is also important for successful adoption (Hussain *et al.*, 2023).

In the context of Malaysian WWTPs, culture-based elements rank third, while environmental factors follow as the fourth most critical enablers. Respondents stress teamwork (ECul2) (Kaswan & Rathi, 2019), effective communication (ECul3) (Pandey *et al.*, 2018), and strategic team selection (ECul1) in GLSS as important (Letchumanan *et al.*, 2022; Mishra, 2022). Embracing diverse employee skills is key to enhancing organizational culture (Singh *et al.*, 2021). Strong teamwork cultivates adaptability, confidence in new approaches, and solid employee relations amidst business changes emphasized by Singh *et al.* (2021). Employee involvement ensures cooperative cultures, key to successful GLSS adoption (Rathi *et al.*, 2023). Transparent communication, facilitated by an efficient organizational structure, supports positive work environments (Hariyani *et al.*, 2023). In addition, companies respond to eco-friendly demands by adopting strategies like efficient manufacturing, green procurement, and waste reduction (Pandey *et al.*, 2018). This approach mitigates costs amid market unpredictability (Kumar *et al.*, 2015; Hariyani & Mishra, 2023).

The lowest agreement was observed regarding linkage-based enablers, as seen in Habidin & Yusof (2013), specifically in supplier relationships. Connecting GLSS with customers and suppliers (ELnk4) and prioritizing customer satisfaction (ELnk2) scored lowest in this study. A notable decrease in consumer complaints reflects a customer-focused social performance (Pandey *et al.*, 2018), emphasizing product responsibility (Farrukh *et al.*, 2020). Organizations supporting suppliers' environmental shifts through training, workshops, and financial aid (Hussain *et al.*, 2023) foster long-term customer relationships by responding to their expectations and concerns (Farrukh *et al.*, 2021).

## 5. CONCLUSION

This study aims to assess the enablers influencing GLSS implementation in Malaysia's wastewater treatment industry, which are crucial for ensuring effective implementation and reaping associated benefits. Understanding the complex and diverse elements affecting GLSS implementation is essential. Data from 296 certified professionals in Malaysian WWTPs were utilized, and SEM validated the research model through EFA, CFA, reliability, and model fit tests, confirming the factors' validity and reliability. The study reveals five significant enablers for GLSS implementation in Malaysian WWTPs. Overall, the majority of Malaysian WWTPs demonstrated a moderate to high level of agreement in GLSS adoption, signalling positive progress in enhancing sustainable performance.

Theoretical implications of this research enrich specialized literature through the originality of the CFA model, allowing examination of GLSS enabler dimensions in the context of WWTP operation. Particularly, the 'strategic' and 'resource' enablers emerged as highly crucial for GLSS implementation in Malaysian WWTPs. Key components include top management commitment, effective project leadership, and precise data collection within

Malaysian contexts. Active support and resource provision by management are important for successful implementation (Kaswan & Rathi, 2019). Moreover, securing resource allocation and funding (Kumar *et al.*, 2015; Hussain *et al.*, 2023), providing necessary awareness training for employee skills (Singh *et al.*, 2021), and external support, such as consultant expertise, are essential (Pandey *et al.*, 2018). Thoughtful financial planning by management ensures adequate allocation of resources to meet project goals (Yadav *et al.*, 2021). The research findings are robust and support the stability of the proposed conceptual CFA model.

Besides theoretical implications, this study also reveals practical implications. It provides a clear picture for WWTP organizations to adopt GLSS enablers for sustainable operations, prioritizing GLSS strategies to improve wastewater treatment processes. WWTP top management should support their teams in fostering effective teamwork, communication, and scheduling through initiatives like employee retention, empowerment, and knowledge sharing, creating a more conducive environment for sustainability-focused organizational culture and ethics. Integrating GLSS into core business strategies aligns with environmental, social, and corporate governance principles to support Sustainable Development Goals.

This study has limitations worth noting and suggests future research directions. First, the sample comprises WWTP professionals only from Malaysia, limiting generalizations attributable to specific country characteristics, culture, and the degree of GLSS implementation. Future research should conduct cross-country comparative analyses to ascertain the universality of the proposed model. Second, exploring the structural relationship between these enablers and sustainable performance in future research is planned. Developing sustainable performance metrics considering economic, environmental, and social aspects will aid the WWTP industry in evaluating its sustainable performance. Future research aims to address these limitations by combining the use of quantitative methods.

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

## CONFLICT OF INTEREST

The authors declare there is no conflict.

## REFERENCES

Abdul-Rashid, S. H., Sakundarini, N., Ghazilla, R. A. R. & Thurasamy, R. (2017) The impact of sustainable manufacturing practices on sustainability performance: Empirical evidence from Malaysia, *International Journal of Operations & Production Management*, *37* (2), 182–204.

Abu, F., Gholami, H., Mat Saman, M. Z., Zakuan, N. & Streimikiene, D. (2019) The implementation of lean manufacturing in the furniture industry: A review and analysis on the motives, barriers, challenges, and the applications, *Journal of Cleaner Production*, *234*, 660–680.

Caiado, R., Nascimento, D., Quelhas, O., Tortorella, G. & Rangel, L. (2018) Towards sustainability through Green, Lean and Six Sigma integration at service industry: Review and framework, *Technological and Economic Development of Economy*, *24* (4), 1659–1678.

Christou, A., Beretsou, V. G., Iakovides, I. C., Karaolia, P., Michael, C., Benmarhnia, T., Chefetz, B., Donner, E., Gawlik, B. M., Lee, Y. & Lim, T. T. (2024) Sustainable wastewater reuse for agriculture, *Nature Reviews Earth and Environment*, *5* (7), 504–521.
de Freitas, J. G., Costa, H. G. & Ferraz, F. T. (2017) Impacts of Lean Six Sigma over organizational sustainability: A survey study, *Journal of Cleaner Production*, *156*, 262–275.
Dieste, M., Panizzolo, R., Garza-Reyes, J. A. & Anosike, A. (2019) The relationship between lean and environmental performance: Practices and measures, *Journal of Cleaner Production*, *224*, 120–131.
Digalwar, A., Raut, R. D., Yadav, V. S., Narkhede, B., Gardas, B. B. & Gotmare, A. (2020) Evaluation of critical constructs for measurement of sustainable supply chain practices in lean-agile firms of Indian origin: A hybrid ISM-ANP approach, *Business Strategy and the Environment*, *29* (3), 1575–1596.
Ershadi, M. J., Qhanadi Taghizadeh, O. & Hadji Molana, S. M. (2021) Selection and performance estimation of Green Lean Six Sigma projects: A hybrid approach of technology readiness level, data envelopment analysis, and ANFIS, *Environmental Science and Pollution Research*, *28* (23), 29394–29411.
Farrukh, A., Mathrani, S. & Taskin, N. (2019) 'Success factors of a combined Green, Lean, and Six Sigma strategy for environmental performance', *2019 IEEE Asia-Pacific conference on computer science and data engineering, CSDE 2019*, pp. 1–18.
Farrukh, A., Mathrani, S. & 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 (Switzerland)*, *12* (19), 8247.
Farrukh, A., Mathrani, S. & Sajjad, A. (2021) A comparative analysis of green-lean-six sigma enablers and environmental outcomes: A natural resource-based view, *International Journal of Lean Six Sigma*, *15* (3), 481–502.
Farrukh, A., Mathrani, S. & Sajjad, A. (2022) A natural resource and institutional theory-based view of green-lean-six sigma drivers for environmental management, *Business Strategy and the Environment*, *31* (3), 1074–1090.
Farrukh, A., Mathrani, S. & Sajjad, A. (2023a) An exploratory study of green-lean-six sigma motivators for environmental sustainability: Managerial insights from a developed and developing economy, *Business Strategy and the Environment*, *32* (8), 5187–5210.
Farrukh, A., Mathrani, S. & Sajjad, A. (2023b) Green-lean-six sigma practices and supporting factors for transitioning towards circular economy: A natural resource and intellectual capital-based view, *Resources Policy*, *84*, 103789.
Gandhi, N. S., Thanki, S. J. & Thakkar, J. J. (2018) Ranking of drivers for integrated lean-green manufacturing for Indian manufacturing SMEs, *Journal of Cleaner Production*, *171*, 675–689.
Gholami, H., Jamil, N., Mat Saman, M. Z. M. Z., Streimikiene, D., Sharif, S. & Zakuan, N. (2021) The application of Green Lean Six Sigma, *Business Strategy and the Environment*, *30* (4), 1913–1931.
Habidin, N. F. & Yusof, S. M. (2013) Critical success factors of Lean Six Sigma for the Malaysian automotive industry, *International Journal of Lean Six Sigma*, *4* (1), 60–82.
Hair, J. F., Black, W. C., Babin, B. J. & Anderson, R. E. (2019) *Multivariate Data Analysis*. (Pearson New International, Ed.) (8th edn). Essex: Cengage.
Hariyani, D. & Mishra, S. (2022) Drivers for the adoption of integrated Sustainable Green Lean Six Sigma agile manufacturing system (ISGLSAMS) and research directions, *Cleaner Engineering and Technology*, *7*, 100449.
Hariyani, D. & Mishra, S. (2023) An analysis of drivers for the adoption of integrated sustainable-green-lean-six sigma-agile manufacturing system (ISGLSAMS) in Indian manufacturing industries, *Benchmarking*, *30* (4), 1073–1109.
Hariyani, D., Mishra, S. & Sharma, M. K. (2024) A descriptive statistical analysis of enablers for integrated sustainable-green-lean-six sigma-agile manufacturing system (ISGLSAMS) in Indian manufacturing industries, *Benchmarking*, *30* (3), 1073–1109.
Hashemi, A., Gholami, H., Venkatadri, U., Sattarpanah Karganroudi, S., Khouri, S., Wojciechowski, A. & Streimikiene, D. (2022) A new direct coefficient-based heuristic algorithm for set covering problems, *International Journal of Fuzzy Systems*, *24* (2), 1131–1147.
Henseler, J., Ringle, C. M. & Sarstedt, M. (2015) A new criterion for assessing discriminant validity in variance-based structural equation modeling, *Journal of the Academy of Marketing Science*, *43* (1), 115–135.
Hundleby, J. D. & Nunnally, J. (1968) Psychometric theory, *American Educational Research Journal*, *5* (3), 431–433.
Hussain, K., He, Z., Ahmad, N., Iqbal, M. & Nazneen, S. (2023) Mapping Green, Lean, Six Sigma enablers through the lens of a construction sector: An emerging economy's perspective, *Journal of Environmental Planning and Management*, *66* (4), 779–812.

Ishak, A., Mohamad, E. & Arep, H. (2022a) The application of six sigma for process control analysis in the Malaysian poultry wastewater treatment, *Journal of Ecological Engineering*, *23* (5), 116–129.
Ishak, A., Mohamad, E., Hambali, A. & Johari, N. L. (2022b) The reliability and process capability assessment of suspended growth sewage treatment plant in Melaka, Malaysia, *Water Science and Technology*, *86* (9), 2233–2247.
Ismail, H., Syed Hussain, T. P. R. & Subhan, M. (2020) The impact of spatial development on water pollution: A comparative assessment of river water quality in two municipalities in Malaysia, *International Journal of Environment and Sustainable Development*, *19* (4), 333–342.
Kaswan, M. S. & Rathi, R. (2019) Analysis and modeling the enablers of Green Lean Six Sigma implementation using interpretive structural modeling, *Journal of Cleaner Production*, *231*, 1182–1191.
Kaswan, M. S. & Rathi, R. (2020a) Green Lean Six Sigma for sustainable development: Integration and framework, *Environmental Impact Assessment Review*, *83*, 106396.
Kaswan, M. S. & Rathi, R. (2020b) Investigating the enablers associated with implementation of Green Lean Six Sigma in manufacturing sector using Best Worst Method, *Clean Technologies and Environmental Policy*, *22* (4), 865–876.
Kozaki, D., Rahim, M. H. b. A., Mohd Faizal, W. I., Yusoff, M. M., Mori, M., Nakatani, N. & Tanaka, K. (2016) Assessment of the river water pollution levels in Kuantan, Malaysia, using ion-exclusion chromatographic data, water quality indices, and land usage patterns, *Air, Soil and Water Research*, *9*, 1–11.
Kumar, S., Kumar, N. & Haleem, A. (2015) Conceptualisation of Sustainable Green Lean Six Sigma: An empirical analysis, *International Journal of Business Excellence*, *8* (2), 210–250.
Letchumanan, L. T., Yusof, N. M., Gholami, H. & Ngadiman, N. H. A. B. (2021) Green Lean Six Sigma: A review, *Journal of Advanced Research in Technology and Innovation Management*, *1* (1), 33–40.
Letchumanan, L. T., Gholami, H., Yusof, N. M., Ngadiman, N. H. A. B., Salameh, A. A., Štreimikienė, D. & Cavallaro, F. (2022) Analyzing the factors enabling Green Lean Six Sigma implementation in the Industry 4.0 Era, *Sustainability (Switzerland)*, *14* (6), 3450.
Mishra, M. N. (2022) Identify critical success factors to implement integrated Green and Lean Six Sigma, *International Journal of Lean Six Sigma*, *13* (4), 765–777.
Mohan, J., Rathi, R., Kaswan, M. S. & Nain, S. S. (2022) Green Lean Six Sigma journey: Conceptualization and realization, *Materials Today: Proceedings*, *50*, 1991–1998.
Nagadi, K. (2022) Implementation of Green, Lean and Six Sigma operations for sustainable manufacturing, A review, *International Journal of Production Management and Engineering*, *10* (2), 159–171.
O'Leary-Kelly, S. W. & Vokurka, R. J. (1998) The empirical assessment of construct validity, *Journal of Operations Management*, *16* (4), 387–405.
Pandey, H., Garg, D. & Luthra, S. (2018) Identification and ranking of enablers of Green Lean Six Sigma implementation using AHP, *International Journal of Productivity and Quality Management*, *23* (2), 187–217.
Parmar, P. S. & Desai, T. N. (2019) A systematic literature review on Sustainable Lean Six Sigma: Current status and future research directions, *International Journal of Lean Six Sigma*, *11* (3), 429–461.
Parmar, P. S. & Desai, T. N. (2020) Evaluating Sustainable Lean Six Sigma enablers using fuzzy DEMATEL: A case of an Indian manufacturing organization, *Journal of Cleaner Production*, *265*, 121802.
Rahman, M. & James, O. (2019) A Lean, Green and Six Sigma (LG6$\sigma$) for SMEs in leather industry in Bangladesh, *International Journal of Knowledge, Innovation and Entrepreneurship*, *7* (2), 42–66.
Rathi, R., Kaswan, M. S., Antony, J., Cross, J., Garza-Reyes, J. A., Furterer, S. L. & Furterer, S. L. (2023) Success factors for the adoption of Green Lean Six Sigma in healthcare facility: An ISM-MICMAC study, *International Journal of Lean Six Sigma*, *14* (4), 864–897.
Rimantho, D. & Nugraha, Y. W. (2020) Wastewater quality control analysis in the pharmaceutical industry using process capability approach, *ARPN Journal of Engineering and Applied Sciences*, *15* (5), 716–723.
Sagnak, M. & Kazancoglu, Y. (2016) Integration of green lean approach with six sigma: An application for flue gas emissions, *Journal of Cleaner Production*, *127*, 112–118.
Shokri, A. & Li, G. (2020) Green implementation of Lean Six Sigma projects in the manufacturing sector, *International Journal of Lean Six Sigma*, *11* (4), 711–729.
Shokri, A., Antony, J. & Garza-Reyes, J. A. (2022) A new way of environmentally sustainable manufacturing with assessing transformation through the green deployment of Lean Six Sigma projects, *Journal of Cleaner Production*, *351*, 131510.
Siegel, R., Antony, J., Garza-Reyes, J. A., Cherrafi, A. & Lameijer, B. (2019) Integrated Green Lean approach and sustainability for SMEs: From literature review to a conceptual framework, *Journal of Cleaner Production*, *240*, 118205.

Singh, M. & Rathi, R. (2022) Empirical investigation of Lean Six Sigma enablers and barriers in Indian MSMEs by using multi-criteria decision making approach, *Engineering Management Journal*, *34* (3), 475–496.

Singh, M. & Rathi, R. (2023) Implementation of environmental Lean Six Sigma framework in an Indian medical equipment manufacturing unit: A case study, *TQM Journal*, *36* (1), 310–339.

Singh, M., Rathi, R. & Garza-Reyes, J. A. (2021) Analysis and prioritization of Lean Six Sigma enablers with environmental facets using best worst method: A case of Indian MSMEs, *Journal of Cleaner Production*, *279*, 123592.

United States Environmental Protection Agency (2007) *The Lean and Environment Toolkit*. Washington, DC: USEPA Sustainability.

Von Sperling, M., Verbyla, M. E. & Oliveira, S. M. (2020) *Assessment of Treatment Plant Performance and Water Quality Data: A Guide for Students, Researchers and Practitioners*. London: IWA Publishing.

Yadav, G. & Desai, T. N. (2017) Analyzing Lean Six Sigma enablers: A hybrid ISM-fuzzy MICMAC approach, *TQM Journal*, *29* (3), 488–510.

Yadav, N., Shankar, R. & Singh, S. P. (2021) Critical success factors for Lean Six Sigma in quality 4.0, *International Journal of Quality and Service Sciences*, *13* (1), 123–156.

Yadav, V., Gahlot, P., Duhan, R. K. & Phanden, R. K. (2023a) *Analysing Relationship Among Lean Six Sigma Critical Success Factors: An Interpretive Structural Modeling Approach*. Lecture Notes in Mechanical Engineering. Singapore: Springer Nature Singapore.

Yadav, V., Kaswan, M. S., Gahlot, P., Duhan, R. K., Garza-Reyes, J. A., Rathi, R., Chaudhary, R. & Yadav, G. (2023b) Green Lean Six Sigma for sustainability improvement: A systematic review and future research agenda, *International Journal of Lean Six Sigma*, *14* (4), 759–790.

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