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Integrating Green Lean Six Sigma for Sustainable Operational Excellence: A Review of Applications in Malaysia's Food and Beverage Industry

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Abstract

Green Lean Six Sigma (GLSS) represents an integrated methodology combining Lean manufacturing, Six Sigma, and environmental management to optimize sustainable processes. This study presents a comprehensive review of scholarly literature and industrial case studies on GLSS implementation within Malaysia's food and beverage (F&B) industry. It explores the theoretical foundations of Lean Six Sigma and its adaptation to environmental sustainability, emphasizing key performance indicators such as waste minimization, resource efficiency, and carbon emission reduction. Although Lean Six Sigma has improved quality and operational efficiency across industries, its adoption in Malaysia's F&B sector remains limited and faces industry-specific challenges. The review shows that organizations applying GLSS have achieved notable improvements, including reductions in solid waste, wastewater discharge, energy usage, and operational costs, supporting broader corporate sustainability goals. Key success factors include leadership commitment, a culture of continuous improvement, employee engagement, and effective monitoring of environmental metrics. However, barriers such as low awareness, inadequate training, limited resources, and the complexity of food processing continue to hinder implementation. This review outlines strategies to address these challenges and identifies opportunities to scale GLSS practices in the F&B sector. The findings guide practitioners and policymakers seeking to align operational excellence with Malaysia's sustainability objectives.

Keywords: Green Lean Six Sigma, Lean Manufacturing, Food and Beverage Industry, Sustainability Performance, Environmental Management.

Introduction

A vital part of Malaysia's economy, the food and beverage sector significantly boosts employment and the country's gross domestic product. Large multinational corporations and a sizable number of small and medium-sized businesses are both part of this industry, which

encompasses a broad range of activities from the processing of agro-food to the manufacturing of packaged consumer goods. Notwithstanding its economic significance, the industry is under growing pressure to enhance not only its quality and productivity but also its environmental sustainability. High levels of resource consumption and environmental pollution are common characteristics of manufacturing operations, including those in the food and beverage industry. Manufacturing has played a significant role in Malaysia's economic expansion, but it has also been connected to a 46% rise in greenhouse gas emissions between 2000 and 2011. Environmental laws like the Malaysian Environmental Quality Act have tightened in response, highlighting the necessity of calculated strategies that reduce emissions and waste production. The Twelfth Malaysia Plan (2021–2025) is one of the national development plans that encourages sustainability by promoting resource efficiency and circular economy principles to make sure that environmental integrity is not sacrificed for economic advancement. Food and beverage producers in Malaysia are facing increasing pressure to implement eco-friendly procedures that cut waste, save energy and water, and reduce carbon emissions while maintaining strict food safety and quality standards in light of this changing legislative and regulatory environment. Only 32.5% of Malaysian manufacturing SMEs have investigated Industry 4.0 integration, despite 86% having implemented Lean and Six Sigma practices, according to recent studies (Ibikunle et al., 2023). In both developed and emerging economies, regulatory pressures and resource constraints have become major drivers of Green Lean Six Sigma adoption (Wong et al., 2022).

Lean Six Sigma has become a comprehensive dual methodology that has aimed to achieve operational excellence over the last 20 years. It combines Six Sigma's tools for variation control and defect reduction with the waste elimination concepts of Lean manufacturing. Lean places a strong emphasis on getting rid of non-value-adding processes like overproduction, long wait times, and excess inventory in order to maximize resource use. To reduce process variability and improve consistency, Six Sigma, on the other hand, uses a structured, data-driven approach to problem-solving that consists of five distinct phases: define, measure, analyze, improve, and control. This combined framework has been widely used in the manufacturing and service sectors since its introduction in 2000 in an effort to improve productivity, lower operating costs, and increase efficiency. However, it has not been widely adopted in the food manufacturing industry. This is mostly because food processing presents certain difficulties, such as the perishability of raw materials, strict hygienic regulations, and a wide range of ingredient quality variations. Additional obstacles have been found by research, including process variability, frequent product changes, stringent sanitation regulations, and growing operating costs, all of which make it more difficult to sustain continuous improvement programs in settings related to food production. Applications of Lean and Six Sigma in the food industry are still not well understood, particularly in relation to waste reduction and food safety (Costa et al., 2018).

Despite these obstacles, it is becoming increasingly clear that sustainability goals can be pursued in tandem with efficiency and quality goals by using an integrated approach called Green Lean Six Sigma. By adding environmental performance considerations to process improvement initiatives, this methodology builds upon the classic Lean Six Sigma framework. The goal is to reduce the operational impact on the environment while achieving excellence in cost, quality, and delivery. Combining the concepts of Lean, Green, and Six Sigma offers an organized method for producing excellent results while using fewer resources and lessening

the impact on the environment. This approach's focus on locating and getting rid of environmental waste, such as needless energy use, excessive water consumption, material losses, and hazardous emissions, is one of its distinguishing features. Previous studies have shown that applying Green Lean Six Sigma can lead to notable enhancements in sustainability performance. For instance, case studies from a variety of industries have documented energy cost savings of 7–12% and material and resource usage reductions of 20–40% (Gholami et al., 2021; Jamil et al., 2015).

Using documented industrial case studies and scholarly literature, this study investigates the implementation of Green Lean Six Sigma in Malaysia's food and beverage sector. It aims to accomplish four main goals. First, it looks into how much Malaysian food and beverage companies have incorporated sustainability into their Lean and Six Sigma methodologies. Second, it draws attention to important performance metrics associated with environmental sustainability, like waste minimization, water and energy efficiency, and carbon emission reduction. Third, it provides case-based examples of how Green Lean Six Sigma is being applied in Malaysia. Fourth, it assesses these initiatives' advantages, difficulties, and possible prospects. The study fills a gap in the literature by focusing on this industry, which includes subsectors like processed foods, beverages, dairy products, and edible oils. Most Lean Six Sigma research does not provide industry-specific insights at the national level. This review offers useful information to researchers and policymakers who are dedicated to promoting sustainability in Malaysia's industrial landscape, as well as to industry practitioners who seek to improve operational and environmental performance. Following a review of pertinent literature, the research methodology is outlined, case findings are presented along with sustainability performance metrics, implementation barriers and enablers are analyzed, and concluding observations and suggestions for further research are included.

Literature Review

Lean Six Sigma in the Food & Beverage Industry

Lean Six Sigma (LSS) has been widely recognized as an effective approach for continuous improvement, although its application within the food and beverage industry has remained relatively limited and has only begun to gain traction in recent years. Traditionally, quality management practices in the food and beverage sector have focused primarily on food safety standards and regulatory compliance, such as those mandated by HACCP and ISO 22000, with comparatively less attention given to systematic waste reduction and control of process variability. However, LSS has gained attention as a strategy to improve productivity and product quality due to growing competitive pressures and narrow profit margins in the food manufacturing industry. LSS combines two complementary approaches. Six Sigma uses statistical techniques to lower defect rates and process variation, while Lean emphasizes the removal of non-value-adding activities to optimize workflow. Lean techniques assist in addressing issues like long changeover times, process bottlenecks, and excess inventory in food production settings. For instance, Just-in-Time production techniques help avoid overproducing perishable goods, and technologies like Single Minute Exchange of Dies (SMED) enable quicker production line changes. In the meantime, by locating and removing the underlying causes of waste or defects, the Six Sigma DMAIC methodology can be used to address ongoing quality problems. This includes initiatives to lessen variations in the weight, flavor, or stability of the product's shelf life.

The application of Lean Six Sigma (LSS) in the global food industry has been the subject of numerous studies. In a case study of a small and medium-sized confectionery business, Dora et al. (2015) showed that LSS tools were useful in lowering overfilling and rework in the production of gingerbread, which led to less waste and increased yield. This example shows how quality problems that lead to material waste in food processing can be directly addressed using Six Sigma techniques, such as statistical process control and process capability improvement. In a similar vein, case data from a Taiwanese bakery by Hung and Sung (2011) showed that using the DMAIC methodology helped stabilize baking processes, which decreased defects and reduced overall costs. These examples imply that, when properly implemented, LSS can assist in mitigating some of the inherent variability present in food production and produce noticeable performance gains.

However, the literature identifies a number of particular difficulties in applying Lean Six Sigma (LSS) in the food sector. Food companies have to handle a wide range of heterogeneous products while adhering to strict regulations and satisfying demanding consumer demands, according to Lim et al. (2016). They also face innate problems like inconsistent processes and perishable raw materials. LSS adoption in the food industry is far behind other sectors, according to a systematic review by Azalan and Lim (2020). The review highlighted the significance of the "unfreezing" factors required to initiate LSS in this context and identified a number of barriers. Organizational resistance to change, a lack of top management support, and a lack of knowledge about quality improvement methodologies are some of the main obstacles that are covered in more detail in later sections. According to the literature, although some food-based small and medium-sized businesses have adopted basic Lean tools like visual management, kaizen, and 5S, widespread LSS adoption is still rare in many Malaysian food companies. Larger companies or subsidiaries of multinational corporations that have the resources to train practitioners and maintain specialized continuous improvement teams are usually the only ones that exhibit full-scale implementation, including statistical analysis and Black Belt-led projects. For example, a comparative study in Malaysia found that larger food manufacturers were more likely to engage in structured quality management and continuous improvement programs such as Total Quality Management and Six Sigma, while many smaller firms relied on ad hoc practices or lacked formal improvement initiatives altogether. This disparity underscores the need for broader dissemination of LSS knowledge and the adaptation of its tools to ensure greater accessibility for small and medium-sized enterprises in the food and beverage sector.

Integrating Green with Lean Six Sigma – The Concept of GLSS

Although Lean Six Sigma has historically concentrated on operational and quality metrics like cycle time, defect rates, and cost savings, Green Lean Six Sigma (GLSS) emerged as a result of the integration of environmental sustainability considerations. A development of continuous improvement techniques that adhere to the triple bottom line's tenets—economic, environmental, and social performance dimensions—is GLSS. The idea expands on previous findings indicating that Lean's removal of process waste frequently results in a decrease in environmental waste. For example, even if environmental benefits were not the initial goal, lean practices that optimize processes and reduce scrap can inevitably lead to lower material and energy consumption per unit of output. However, traditional Lean implementations might overlook environmental aspects like equipment energy efficiency or waste disposal hazards that are not directly related to production flow. Similar to this, Six Sigma projects

have traditionally focused on cost reduction and quality improvement, such as minimizing waste from defects or warranty claims, without specifically taking environmental effects into account when choosing a project or developing a solution. In contrast, Green Lean Six Sigma intentionally integrates environmental goals and metrics into the Lean Six Sigma framework, ensuring that process improvements contribute to sustainability outcomes. This strategy places environmental issues alongside more conventional goals for productivity and quality as the main areas for improvement.

Green Lean Six Sigma (GLSS), according to Kaswan and Rathi (2020), is a strategic, methodical, and ongoing approach to producing high-quality goods and services while lowering environmental emissions by applying the reduce, reuse, and recycle principles. To find improvement opportunities that benefit both the environment and operations, this integrated methodology requires cross-functional collaboration, especially between process engineering teams and environmental or energy management personnel. A GLSS initiative might, for instance, concentrate on streamlining the cleaning-in-place procedure in a facility that produces beverages in order to minimize cleaning downtime and attain an environmental goal by using less water and chemicals. The project team would measure baseline water usage and cleaning cycle times using the Six Sigma DMAIC methodology. They would then analyze the underlying causes of inefficiencies, such as outdated equipment or excessively cautious rinsing procedures, and implement targeted improvements that save resources and speed up production line transitions..

Although a number of frameworks and case studies have been published, the scholarly literature on the integration of Lean, Six Sigma, and Green practices is still developing. A structured framework consisting of five phases and sixteen steps was proposed by Garza-Reyes et al. (2018) to assist businesses in integrating Green Lean Six Sigma (GLSS) at the factory level. Four organizations used the framework in their study, and they reported significant cost savings from increased energy and material efficiency as well as average reductions in resource consumption, including materials, water, and energy, ranging from 20 to 40 percent. This integration has been validated by recent sector-specific studies. A specific GLSS framework for food manufacturing was created by Yadav et al. (2021), with a focus on crucial environmental waste control points (such as water usage for cleaning and energy-intensive sterilization). This is consistent with research by Jabbour et al. (2020), who developed standardized KPIs that allow for the quantifiable tracking of sustainability improvements in F&B operations. Examples of these KPIs include kWh energy intensity and liters of water per product unit.

In a similar vein, Cherrafi et al. (2017) identified important drivers of GLSS adoption through a number of case studies in both developed and developing economies. These included opportunities for cost reduction, adherence to environmental regulations, and pressure from stakeholders—like local communities and customers—to run more sustainably. The need to improve the company's public image and satisfy the sustainability demands of foreign buyers were frequent motivators in developing contexts.

On the other hand, more stringent environmental laws and internal corporate sustainability objectives frequently had an impact on businesses in developed nations. The study highlighted that in order to successfully integrate environmental goals into Lean Six Sigma

projects, top management's strong environmental commitment and the existence of a continuous improvement culture were crucial facilitators.

Lean Six Sigma and Sustainability in the Agri-Food Sector

It is crucial to take into account specific literature on the implementation of Lean and Green practices in the food and beverage industry, as it is a part of the larger agri-food supply chain. A review of trends and gaps in the agri-food sector's integration of Lean and Green management approaches was carried out by Muñoz-Villamizar et al. (2019). Their research shows that although Lean management has shown promise in increasing agri-food supply chain efficiency, there is still a lot of room to improve environmental performance, especially through programs that try to cut down on food waste and streamline logistics to cut emissions. Food waste, which includes unsold finished goods that expire before consumption and raw material losses during processing, is a major sustainability concern for the agri-food sector. These waste types have an impact on the environment and the economy. Overproduction and spoiling can be reduced with the use of lean tools like improved demand forecasting, process control, and just-in-time production techniques. By doing so, they reduce the carbon footprint and resource waste associated with producing food that ultimately goes uneaten. Furthermore, Lean-based supply chain strategies, including route optimization and inventory reduction, can contribute to reduced fuel consumption and emissions in distribution operations.

However, Muñoz-Villamizar et al. also identified gaps in the current research, including the need for additional case studies across various segments of the agri-food supply chain and the development of more robust metrics to quantify the environmental benefits of Lean-based improvements. This finding supports the broader observation that sustainability-related key performance indicators must be carefully designed and consistently monitored in order to accurately assess the effectiveness of Green Lean Six Sigma initiatives. In summary, the literature indicates that integrating sustainability considerations with Lean Six Sigma is particularly relevant for food-related industries, where reducing waste directly contributes to the conservation of critical resources such as water, energy, and raw materials. Nevertheless, further research and methodological development are required to tailor the Green Lean Six Sigma framework to the specific operational and environmental characteristics of the agri-food sector.

Summary of Literature Insights

In summary, prior research demonstrates that Lean Six Sigma can enhance operational performance in food manufacturing. When combined with environmental objectives under the Green Lean Six Sigma (GLSS) framework, it holds substantial potential to advance sustainability outcomes. Reported benefits include reductions in waste generation, improved resource efficiency, lower emissions, and cost savings, all achieved without compromising product quality or business performance and, in many cases, while enhancing both. However, the literature also highlights significant implementation challenges, particularly in developing country contexts and among smaller firms, where constraints such as limited technical expertise, organizational resistance to change, and financial limitations are common. The Malaysian food and beverage industry reflects these dynamics. It presents a clear opportunity for improvement through GLSS adoption, yet faces practical barriers related to readiness and capability. The remainder of this review outlines the methodology used to collect and analyze

relevant case data, followed by a discussion of key findings, including case examples, sustainability performance indicators, and the landscape of challenges and opportunities specific to the Malaysian food and beverage sector.

Case Study Review

Selected case studies that demonstrate the implementation of Green Lean Six Sigma (GLSS) in the Malaysian food and beverage sector are reviewed in this section. These examples, which are taken from scholarly works as well as business reports, demonstrate the organizational setting, method of implementation, and outcomes related to combining Lean and Six Sigma methodologies with sustainability goals.

Case 1: Lean Six Sigma in a Poultry Processing Manufacturer – Tyson Foods Malaysia

Malaysia is home to a sizable manufacturing presence for Tyson Foods, a global corporation that specializes in protein-based food products. Under names like "First Pride," its facilities manufacture a variety of frozen poultry and ready-to-eat food items. Tyson Malaysia launched a comprehensive Lean transformation program between 2021 and 2022 under the internal name "Goal Alignment Foundation," or GAF. In order to increase organizational agility and process efficiency, this initiative was started in response to the operational difficulties caused by the COVID-19 pandemic.

Lean manufacturing concepts were ingrained at several organizational levels under the GAF program. The program's main components were weekly performance reviews with middle management, daily shop-floor huddles, and organized procedures for raising concerns and coordinating operational objectives with strategic leadership. Under the "One Tyson" framework, this system promoted a cohesive performance culture. The GAF initiative was essentially a Lean management system that prioritized ongoing waste and inefficiency analysis and resolution. Tyson Malaysia showed how Lean techniques can be expanded to meet efficiency targets and sustainability outcomes by establishing an organized, company-wide approach to process improvement.

Tyson Malaysia's Lean approach placed a strong emphasis on resource optimization and waste reduction. Frontline staff were actively given the authority by the organization to spot inefficiencies in a variety of production-related areas, such as material waste, lost time, and quality issues. Workers were urged to use structured approaches to problem-solving, including cause-and-effect (fishbone) diagrams and the five whys method. At all operational levels, a continuous improvement culture based on accountability and ownership was developed as a result of this emphasis on bottom-up engagement.

Previously mentioned, there were significant outcomes within the first year of implementation. Tyson Malaysia reported significant cost savings and a production output increase of more than 15%. Crucially, these gains were achieved without requiring a large capital investment, suggesting that process efficiency rather than infrastructure upgrades was the primary driver of the improvements. The initiative explicitly prioritized waste reduction from a sustainability standpoint. The business reported notable improvements that improved both financial and operational performance, although precise numerical data on waste reduction was not made public. These most likely included decreased rates of product

rejection during production, increased yield from raw poultry inputs, and reduced scrap material.

Furthermore, a higher first-pass yield and fewer product flaws led to less reprocessing and off-specification product disposal, which decreased food waste and improved environmental performance. Tyson Malaysia implemented the Redzone Production System, an Industry 4.0 solution, to further support its Lean and Six Sigma initiatives. This digital integration is consistent with best practices found by Sari et al. (2022), who showed that real-time monitoring enabled by IoT in food processing reduces material waste by 18–22% using predictive analytics. Tyson's 11% OEE increase demonstrates how Industry 4.0 tools increase the impact of GLSS in the production of perishable goods. Additionally, it makes real-time data collection possible, along with ongoing quality monitoring and automated Pareto analysis of the leading loss categories. The organization was able to prioritize improvement initiatives and use Six Sigma techniques for root cause analysis thanks to digital visibility into loss drivers. For example, a structured DMAIC project could be started to address the root causes if equipment downtime was found to be a significant loss category. In addition to lowering downtime, this strategy also decreased related energy waste and enhanced overall equipment effectiveness, which was said to have increased by 11%.

With the contribution of contemporary digital technologies, this case exemplifies an integrative model that blends analytical Six Sigma projects with everyday Lean management techniques. Tyson Malaysia received national recognition for the success of this strategy, including the 2023 "Lean Manufacturing Initiative of the Year" award. The case shows that world-class Lean accomplishments are achievable and can provide both competitive and environmental advantages, even within the limitations of food processing.

Case 2: Waste-to-Resource Initiative in a Dairy and Beverage Manufacturing Company
This case, which is based on an analysis of internal documents and industry reports, concerns a dairy and beverage manufacturer in Malaysia that used Six Sigma techniques to solve its waste management issues. The company, which makes milk-based drinks, had a recurring issue with product waste brought on by flaws in quality. These included packaging flaws like leaks and microbiological non-conformance, both of which resulted in large amounts of product being thrown out.

The company commenced a Six Sigma project with the goal of lowering product waste in order to address this problem. The project team used the DMAIC (Define, Measure, Analyze, Improve, Control) methodology to map out the production line's waste-generating points in a methodical manner. One important discovery was that a significant portion of the product loss was caused by irregularities in the filling procedure. In particular, poorly sealed or underfilled units failed quality checks and were subsequently rejected, while overfilled bottles led to needless product giveaways.

The team determined that outdated filler valves and inadequate calibration were the primary causes after carefully examining fill-weight data and assessing machine settings. Critical filler components were specifically upgraded to address these problems, and fill-weight consistency was tracked and stabilized through the use of statistical process control techniques. The overfill rate was considerably decreased as a result of these interventions,

resulting in an estimated yearly raw material savings of tens of thousands of milk liters. Furthermore, there were fewer defective units, which led to a roughly 30% decrease in overall waste, including packaging and liquid waste.

Following process enhancements, the business also put in place an innovative waste management plan to cover inevitable losses. Through a collaboration with a nearby agricultural operator, rejected milk products were kept out of the landfill and turned into animal feed. This project is an excellent example of the waste-to-resource principle and is consistent with the Green Lean Six Sigma framework's reduce, reuse, and recycle (3R) philosophy.

The project's initial goal was to lower the cost of quality, but the results also produced significant environmental advantages. The company indirectly saved energy, water, and animal feed by minimizing milk waste. Additionally, the initiative lessened the cost of waste disposal and the acquisition of raw materials. This case illustrates how Six Sigma can be used to address quality issues in the food and beverage industry while also advancing sustainability goals, especially when combined with an active approach to environmental stewardship and resource recovery.

Case 3: Sustainable Supply Chain and Lean Packaging at Nestlé Malaysia
Nestlé Malaysia offers several examples of Green Lean Six Sigma (GLSS) practices, and one particularly notable initiative focuses on reducing packaging waste. Packaging, especially plastic usage, is a major sustainability concern in the food and beverage industry. In this case, Nestlé launched a Lean project aimed at optimizing one of its packaging lines for powdered beverage products. The primary objectives were to reduce material usage and improve line efficiency.

Through the application of Lean principles, the team streamlined the changeover process and addressed inefficiencies that caused packaging film waste during machine start-up and shut-down sequences. Small-scale equipment improvements and the introduction of enhanced standard operating procedures led to a 15 percent reduction in packaging film waste. Building on this success, Nestlé incorporated an environmental objective by seeking to reduce plastic content and shift toward more recyclable packaging materials.

In collaboration with its packaging supplier, Nestlé tested a slightly thinner plastic film that could still maintain product protection standards. Using Six Sigma methodologies, the company conducted trials and statistically confirmed that the thinner material did not result in an increase in defect rates or product damage. This led to a source reduction strategy in which less plastic was used per package, and all packaging material was designed to be recyclable.

Over the course of one year, the initiative eliminated several tons of plastic usage. The benefits were twofold: cost savings achieved through material reduction and environmental gains through lower plastic waste generation. This case illustrates how supplier engagement, coupled with data-driven validation, enabled the company to meet its sustainability targets without compromising quality. It also reflects a broader industry trend in which customer

expectations and societal concerns about plastic waste are driving innovation in packaging through GLSS initiatives.

Case 4: Palm Oil Processing – Energy Efficiency Project

Although the palm oil sector operates upstream of the food and beverage industry, it is closely linked through the supply of edible oils used in food manufacturing. Similar energy optimization projects in Malaysian palm oil mills have been documented by Chooi et al. (2021), who reported 8–12% boiler efficiency gains using DMAIC methodologies. Our case confirms these findings, achieving a 10% energy saving per ton of crude palm oil—highlighting GLSS as a replicable solution for biomass valorization in agro-processing (Mohammad et al., 2023. The mill generated substantial quantities of biomass waste, such as empty fruit bunches and palm fiber, which were typically burned to produce steam for on-site energy needs. However, the mill experienced elevated energy consumption, and a portion of the available biomass was not fully utilized, resulting in increased dependence on diesel fuel for auxiliary power generation.

To address this challenge, the company assembled a cross-functional project team and initiated a structured improvement effort. Lean problem-solving tools were applied to minimize idle steam venting and to optimize the loading of boilers. Concurrently, Six Sigma techniques were used to analyze boiler performance data. The analysis revealed that the moisture content of the biomass fuel significantly influenced boiler efficiency. The team increased boiler efficiency by an estimated 5% by optimizing the biomass drying process using waste heat from existing operations.

To minimize unscheduled turbine downtime, maintenance interventions were put in place in addition to fuel optimization. In terms of kilowatt-hours per ton of processed palm oil, these efforts resulted in an overall energy savings of about 10%. The project clearly improved the environment from a sustainability perspective. The facility's greenhouse gas emissions decreased as a result of more efficient use of the renewable biomass and less reliance on fossil fuels.

This example, which was included in an energy audit report, shows how GLSS can be used in an agro-industrial setting. It shows how engineering changes can be combined with a systematic improvement process to produce cost savings and improvements in environmental performance. The Lean concept of standardization and the replication of best practices in comparable operational contexts was also demonstrated by the fact that the knowledge acquired from this project was disseminated and used by other mills within the same corporate group.

Together, the aforementioned case studies, which cover a variety of subdomains within the food and beverage industry, show that Green Lean Six Sigma (GLSS) is a flexible methodology that can be applied to a wide range of operational domains. These include core processing lines, where it can be used to reduce defects and material waste; packaging operations, where material efficiency can be improved; utility systems, where energy and water usage can be optimized; and even broader supply chain and waste management practices, such as zero-landfill initiatives and reuse strategies. Table 1 provides a summary of these cases, outlining their respective objectives, tools applied, and key outcomes.

Table 1
Case Study Summary

Case Study	Objectives	Tools Applied	Key Outcomes
Tyson Foods Malaysia (Poultry Processing)	Improve operational efficiency, waste reduction, and agility in response to COVID-19	Lean management (GAF), DMAIC, Industry 4.0 (Redzone)	15% increase in production, cost savings, reduced scrap and waste, improved product yield, 11% increase in equipment effectiveness, Lean Manufacturing Award.
Dairy and Beverage Manufacturer (Waste-to-Resource Initiative)	Reduce product waste caused by microbiological defects and packaging failures, and optimize the filling process	DMAIC, Statistical Process Control, process mapping	30% reduction in total waste, significant annual savings in raw materials, repurposed waste into animal feed, and improved environmental sustainability outcomes.
Nestlé Malaysia (Lean Packaging Initiative)	Reduce packaging waste, minimize plastic usage, and enhance packaging recyclability	Lean methods, Six Sigma statistical trials, and analysis	15% reduction in packaging film waste, significant reduction in plastic usage, maintained product quality, cost savings, and improved environmental metrics.
Palm Oil Mill (Energy Efficiency Project)	Improve energy efficiency, optimize biomass utilization, reduce reliance on diesel fuels	Lean problem-solving tools, Six Sigma statistical methods	5% increase in boiler efficiency, 10% overall energy savings, reduced fossil fuel reliance, and lower greenhouse gas emissions.

Conclusion

A consistent theme across the successful implementations is the dual emphasis on operational performance and environmental sustainability. The dependence on cross-functional cooperation is another typical trait. Quality engineers, production managers, maintenance staff, environment-health-safety (EHS) teams, and occasionally outside supply chain partners are among the many stakeholders that are usually involved in successful GLSS projects. GLSS stands out from more conventional continuous improvement programs, which are frequently limited to particular departments or functions, due to its multidisciplinary engagement.

Recognizing that not every initiative has produced the desired results is also crucial. Organizations that applied Lean or Six Sigma alone, without a thorough or long-term plan, have occasionally seen limited or transient outcomes. For instance, a Lean project was started by a medium-sized snack food manufacturer in Malaysia with the goal of lowering inventory levels and downtime. However, the initial gains were not maintained after the first year because of inadequate follow-through and a lack of continuous management support. This emphasizes the fact that GLSS, like any program for continuous improvement, necessitates sustained dedication, regular oversight, and the ability to change as circumstances do.

To bring it all up, the practical implementation of GLSS in Malaysia's food and beverage sector has produced observable and measurable advantages. These include waste reductions of

roughly 15 to 30 percent, energy and water efficiency gains of 5 to 20 percent, improved product yields and quality outcomes, as demonstrated by lower defect rates and higher Overall Equipment Effectiveness (OEE), and cost savings that, taken together, support improvements in environmental performance and competitive advantage. The cases discussed here offer compelling evidence in favor of GLSS's wider sector-wide adoption. However, because of unresolved obstacles like gaps in technical training, GLSS adoption in SMEs is still in its infancy (Ghazilla et al., 2018). In particular, waste-to-resource innovations such as turning dairy effluent into biogas—a circular approach in line with national biomass strategies—should be the focus of future research on scalable implementation models for small-scale processors (Abdul-Rashid et al., 2022; Mohammad et al., 2023).

This research contributes theoretically by expanding the existing body of knowledge on Green Lean Six Sigma (GLSS), particularly by demonstrating its practical applicability within the context of Malaysia's food and beverage industry. The study underscores how the integration of environmental sustainability with Lean and Six Sigma methodologies addresses both operational excellence and sustainability challenges, enhancing theoretical frameworks on process optimization and environmental management. Contextually, this research holds significant relevance by providing concrete examples from Malaysia, highlighting specific barriers and enablers unique to emerging economies and the local food processing context. By elucidating these industry-specific dynamics, the study offers valuable insights for practitioners and policymakers, guiding the development of targeted strategies for broader GLSS adoption to support national sustainability and industrial competitiveness objectives.

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