Exploring the Potential Synergies between Industry 5.0 and Green Lean Six Sigma for Sustainable Performance: A New Dimension of Operational Excellence

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Abstract

Today's companies are adopting a sustainable strategy, often in a reactive manner, to respond to customer demands, stakeholder concerns, and compliance with regulatory requirements, while seeking to proactively maintain a strong standing in the future market. This article explores the synergies between Industry 5.0 technologies and Green Lean Six Sigma (GLSS), highlighting how their integration can catalyse sustainable transformations in manufacturing. The study combines a literature review with empirical survey conducted across companies in various industrial sectors. The objective is to identify and examine potential synergies between Industry 5.0 technologies and Green Lean Six Sigma tools to improve the environmental impact of manufacturing companies. The results highlight the importance of Industry 5.0 technologies in boosting the efficiency of GLSS, thereby promoting more sustainable manufacturing practices. Key areas of synergy include sustainable process optimization, energy efficiency, sustainable personalization, data analytics for sustainability, and sustainable innovation. This article emphasizes the mutual benefits of integrating Industry 5.0 technologies with the Green Lean Six Sigma methodological framework. This combination reduces the consumption of materials and resources, improves energy efficiency, and stimulates innovation in favor of eco-responsible production. It calls for an integrated approach, considering technology, human resources, and processes, to enable manufacturing companies to achieve optimized operational performance while contributing to environmental sustainability.

Keywords: Grean Lean Six Sigma; Industry 5.0; Environmental impact; operational excellence, Sustainable manufacturing practice, sustainable innovation.

1. Introduction

The contemporary economy is marked by an awareness of the environmental and societal issues that companies face. In the face of issues such as climate change and pollution, stakeholders are showing a strong preference for eco-friendly products and services, prompting manufacturing

industries to adopt sustainable practices to reduce their emissions and meet environmental commitments [1-2]. Thus, sustainable manufacturing is emerging as the preferred and economically viable strategy for today's industries, allowing them to develop action plans that minimize pollution and resource use throughout the product life cycle [3]. This trend is further accentuated by growing consumer demand for products from the green economy [4].

In this context, Green Lean Six Sigma emerges as an integrated approach that simultaneously improves the operational and environmental performance of organizations [5]. This methodology, which combines Lean Manufacturing, Six Sigma, and ecological principles, promotes optimal use of resources and paves the way for sustainable development [6]. Adopted by industries for its eco-responsible orientation, it helps to maintain superior product quality, while minimizing waste, anomalies and ecological impact [7].

Similarly, Industry 5.0 marks a significant turning point thanks to its advanced ecological solutions compared to previous industrial transformations [8]. Researchers argue that this newly introduced evolution has the potential to go beyond the profit-centric productivity of Industry 4.0 to contribute equitably to various aspects of sustainable development such as human-centricity, socio-environmental sustainability, and resilience [9-10-11].

Despite that, the current literature offers little insight into how Industry 5.0 technologies can be aligned with Green Lean Six Sigma principles to catalyze sustainable transformation in manufacturing. No previous study directly addresses this synergy. This study seeks to address this gap by investigating how the integration of Industry 5.0 innovations can enhance the effectiveness of Green Lean Six Sigma, thereby promoting more sustainable manufacturing practices. The central objective of this study is to identify and study potential synergies between new Industry 5.0 technologies and the various Green Lean Six Sigma tools to advance the sustainability efforts of manufacturing companies. This approach relies on an analysis of existing literature, enriched by empirical data, to illustrate how the integration of advanced technologies, including artificial intelligence, the Internet of Everything (IoE), and advanced data analytics, can enhance the Green Lean Six Sigma methodology. The findings will provide practitioners with an operational framework to adopt Green Lean Six Sigma strategies, while leveraging the technologies of Industry 5.0 to strengthen the sustainability of their organizations.

2. Methods

To carry out this study, a mixed methodology was adopted, combining literature review and an empirical study with companies in various industrial sectors. This approach enabled the identification of potential synergies between emerging technologies and Green Lean Six Sigma tools and the assessment of their impact on organizations' environmental performance. First, an exhaustive search was conducted in leading academic databases IEEE Xplore, Springer, Science Direct, Taylor & Francis, and MDPI to identify current trends, gaps in existing research, and opportunities for the integration of Industry 5.0 technologies into Green Lean Six Sigma strategies. Relevant articles published within the past decade were selected, including empirical and theoretical studies dealing with Industry 5.0 technologies, GLSS and sustainability in the

manufacturing sector. This review provided an overview of current knowledge and enabled the identification of possible areas of synergy.

Subsequently, a field study is carried out with practitioners and experts in operational excellence from various industrial companies. The questionnaire aimed to collect data on the Industry 5.0 technologies currently being implemented, their integration into Green Lean Six Sigma practices, and the perceived impact on sustainability and operational efficiency. The questions were developed to assess the five identified areas of synergy: sustainable process optimization, energy efficiency and emissions reduction, sustainable personalization, data analytics for sustainability, and sustainable innovation. Qualitative analysis was used to interpret open-ended responses regarding the challenges faced in integrating technologies and the strategies employed to overcome these barriers.

Convergence between Green Lean Six Sigma and Industry 5.0: Identifying potential synergies

Green Lean Six Sigma's philosophy is based on the mutual goals of green, lean and six sigma strategies [12-13]. Lean is used to generate value for consumers by reducing waste and turnaround times and improving process flow [14-15-16]. Identified as an "eco-friendly" [17], it conserves resources by minimizing operational waste such as overproduction, overprocessing, transport and excessive stocks, which has an impact on environmental performance [18]. The Six Sigma method also improves environmental performance by reducing defects and minimizing process variations [19-20]. By identifying and eliminating sources of error and waste in production processes, it also reduces the consumption of raw materials, energy and other resources needed for production.

The green concept mainly focuses on environmental sustainability and resource conservation among its key aspects [21]. The scope of green operations extends from product development to the entire product lifecycle. It encompasses environmental practices such as eco-design, cleaner production, recycling, reuse, delivery, use and dumping of products [22] Through the application of Green Lean and Six Sigma, companies can achieve critical goals such as waste minimization, pollution prevention, process control, energy and resource conservation, while reducing costs [23-24]

In addition, Industry 5.0, by stimulating the circular economy and introducing eco-responsible products to the global market, embodies a commitment to strong environmental values, aiming at the optimization of material flows and an improvement in energy efficiency within companies [25], [26], [27] Recent advances in areas such as AI, IeE, Cloud Computing, Big Data, cyber-physical systems, 5G, alongside digital transformation and the circular economy, are catalyzing the transition to smarter and more sustainable manufacturing [28-29-30] . The convergence between Green Lean Six Sigma and Industry 5.0 offers interesting opportunities to combine the principles of operational efficiency and sustainability with the advanced technologies of Industry 5.0:

Sustainable process optimization: Green Lean Six Sigma emphasizes process optimization to reduce waste and minimize environmental impact. This methodology could greatly benefit from integrating Industry 5.0 innovations to monitor and control operations in real-time, identify sources of waste, and implement continuous improvements to make processes more sustainable.

IoE helps to eliminate bottlenecks in communication channels, reduce waste in the supply chain, and optimize production processes [31-32]. In addition, Smart Additive Manufacturing (SAM) is establishing itself as a cutting-edge technology in the smart manufacturing sector [33]. It helps to reduce the consumption of materials and resources, in addition to its ability to save energy resources, which leads to pollution-free environmental production [31]. To fully exploit the benefits of Industry 5.0, SAM is combined with a built-in automation capability to streamline the processes involved in supply chain management and reduce product delivery time [30]. AI would also be an indispensable technological element of Industry 5.0 as it helps stakeholders make better decisions, reduces information overload, decreases errors, improves occupational safety and health, and promotes the creation of more sustainable products and services [34].

Energy efficiency and emissions reduction: Industry 5.0 offers innovative solutions to improve energy efficiency and reduce carbon emissions in industrial operations [35]. At the heart of this transformation, the Smart Energy Management System (IEMS) is proving to be crucial to move towards sustainable energy management [36] by optimizing the real-time monitoring and control of energy systems, as well as the reliability and efficiency of energy production [37]. In addition, IEMS, combined with technologies such as cloud-based demand response systems, smart storage and charging, microgrids, and blockchain-based peer-to-peer electricity trading, synergistically contributes to bridging the gap between the development of renewable energy resources and their actual use in industrial and commercial operations [4-38]. This approach thus responds to the growing demand for energy due to the digitalization of industrial operations and the increased consumption linked to the rapid evolution of smart products [39]. These technologies can be integrated into Green Lean Six Sigma initiatives to enhance energy efficiency, decrease waste, and lower the carbon footprint of production and logistics process.

Sustainable personalization: Industry 5.0 is characterized by high-precision, low-cost mass customization, introducing sustainable and resilient thinking into human-centered digital transformation and bioeconomic ideals [40]. This can be aligned with the goals of Green Lean Six Sigma in terms of reducing excess inventory and minimizing waste from overproduction. Digital Twins play a key role in product customization, making it possible to develop solutions tailored to individual customer needs, predict and optimize the efficiency and performance of customizable products, reduce the complexity of underlying manufacturing processes, and improve business functions [28-31]. Significantly, the Digital Twins is useful in achieving the sustainability goals of Industry 5.0. By enabling companies to simulate and predict the digital socio-environmental footprint of their products and services, from the design, prototyping and development stage to the end-user consumption phase and end-of-life recovery, digital Twins actively contributes to the industry's alignment with more sustainable practices [41]. By incorporating sustainable production and logistics practices into these customization models, companies can meet customer needs while reducing their environmental impact.

Data analytics for sustainability: Advanced data analytics is a pillar of Industry 5.0. Big Data analytics techniques contribute to real-time decision-making, enabling the recognition and elimination of non-essential elements to maximize predictability and explore new opportunities [42]. Studies highlight the critical role of IoE in improving efficiency, and data-driven decision-making [43]. Immediate data collection enables real-time analysis and decision-making, which

is beneficial to supply chain management services [32-44]. AI's capabilities in fast data processing facilitate automation and in-depth analysis, improving decision-making and enabling organizations to increase efficiency [45]. As part of the Green Lean Six Sigma approach, it is crucial to implement an effective data collection process [46]. By using the data analytics tools brought by Industry 5.0 to monitor environmental and operational performance, companies can identify opportunities for improvement, track progress toward sustainability goals, and make informed data-driven decisions. This helps to optimize results in terms of both operational efficiency and sustainability.

Sustainable innovation: Recent studies unanimously recognize that Industry 5.0 is now integrating sustainability objectives into its ongoing digital transformation [47-48-49-50]. This focus on sustainability and innovation is a key pillar of Industry 5.0, which aims to become an innovative, resilient, socio-centric and competitive industry, while respecting planetary boundaries and minimizing its environmental impact [51]. In line with this trend, there has recently been a lot of attention on sustainable innovation. Academics and practitioners argue that the introduction of innovation into business practices and products should not be driven solely by profit and should address environmental priorities and ensure social well-being [52]. Sustainable innovation is needed more than ever to promote energy-efficient production, cleaner technologies, eco-friendly yet customized products, and an overall sustainable industry [53]. In response, manufacturing sectors are stepping up their efforts by investing heavily in research and development, seeking to design high-quality, eco-friendly products [2]. By combining this approach with Green Lean Six Sigma's continuous improvement practices, companies can develop new sustainable and innovative solutions, such as eco-designed products, more efficient production processes and more sustainable logistics models. Figure 1 below illustrates the potential synergies between Industry 5.0 technologies and Green Lean Six Sigma. By capitalizing on these synergies, companies can create more resilient, efficient, and environmentally friendly operating models, helping to reach their sustainability objectives while remaining competitive in the global marketplace.

Fig. 1. Potential synergies between Industry 5.0 technologies and Green Lean Six Sigma

3. Results

The study was conducted among 70 operational excellence practitioners assess the effect of Industry 5.0 technologies on environmental performance, in line with Green Lean Six Sigma goals, such as sustainable process optimization, innovation, and energy efficiency. A variety of actors from different sectors of activity participated in the study. Figure number 2 below represents the main industrial sectors involved, such as food and beverage, electronics, and

automotive. Most respondents come from the automotive sector, representing 30% of the sample. This diverse distribution suggests a broad representation of key sectors of the economy.

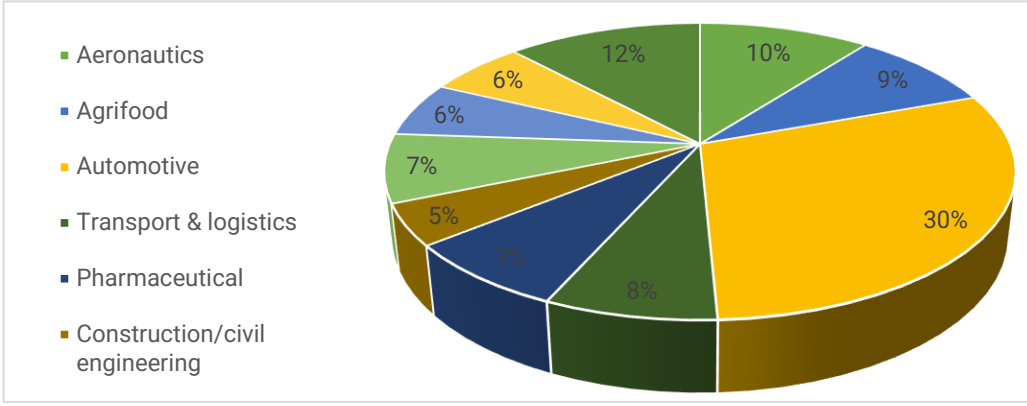

Figure 2: Sectoral Breakdown of Represented Companies

Participants were questioned about the industry 5.0 technologies they have implemented in their organizations to contextualize the study results, as shown in Figure 3 bellow. The results show a variety of cutting-edge technologies adopted by the companies represented to improve their operations and sustainability. Among the technologies mentioned are intelligent automation with the use of Cobots, additive manufacturing, technologies for data transmission, storage, and analysis, as well as those for energy efficiency and renewable energy. In addition, 5G/6G networks and the Internet of Everything (IoE) has been cited as essential components of companies' technology infrastructures to facilitate connectivity and communication. The adoption of these technologies reflects a priority placed on process optimization and data-driven decision-making to increase business performance.

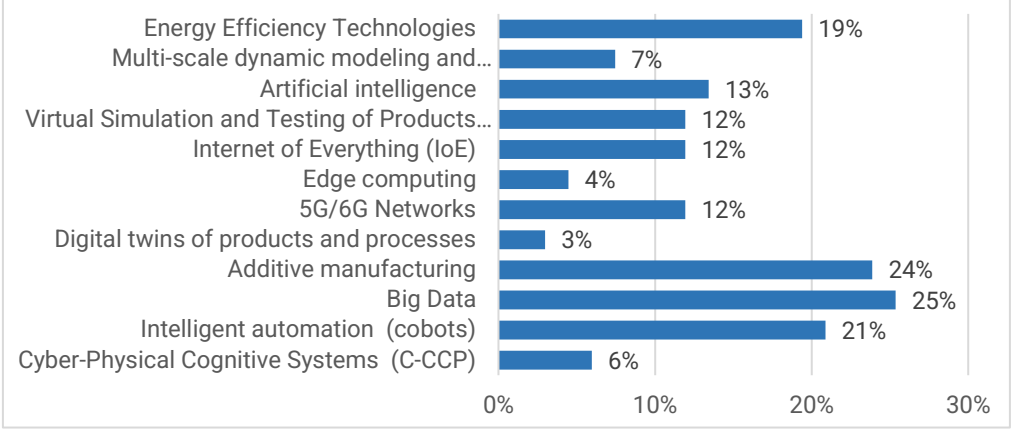

Figure 3: Technologies 5.0 integrated within represented companies

The study examined the influence of Industry 5.0 technologies on sustainable process optimization. Real-time monitoring and real-time data collection, cited by 75% and 69% of respondents respectively, are the areas where the impact of Technology 5.0 is perceived to be the most significant, as illustrated in Figure 4 below. These features promote rapid analysis and agile adjustment, which are essential for sustainable process optimization. Predictive analytics, although less cited with 42% of respondents, is recognized for its role in anticipating and preventing operational problems, thus contributing to a proactive approach to process management. Evidence-based decision-making and high process control were identified as notable advances in sustainable optimization by 67% and 60% of respondents respectively. These results illustrate a growing adoption of data-driven decision-making practices, promoting more accurate and less wasteful process management, aligned with the principles of Green Lean Six Sigma.

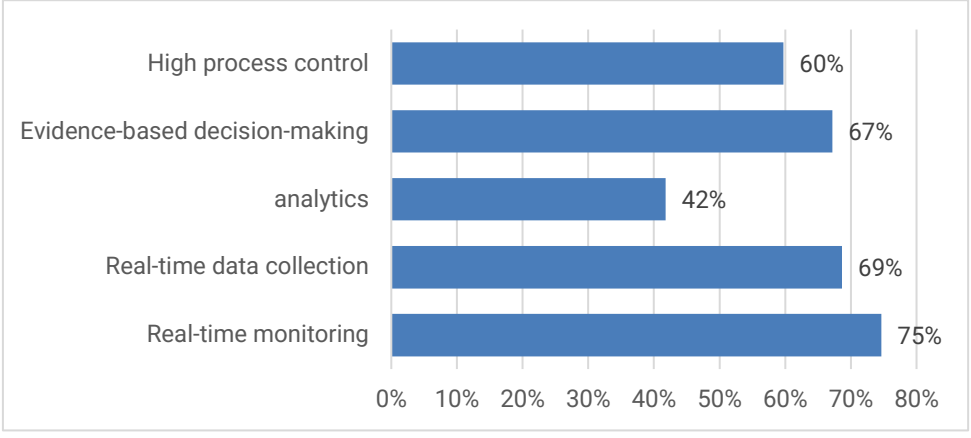

Figure 4: Contribution of Industry 5.0 technologies to sustainable process optimization

In addition, respondents rated the improvement in business process optimization attributable to 5.0 technologies on a scale of 5. Figure 5 below shows the distribution of the assessment of the impact of 5.0 technologies on sustainable process optimization, as perceived by respondents. Specifically, 52% of respondents gave a score of 4, reporting a high improvement, while 18% considered the improvement to be substantial with a score of 5. Only 5% of respondents felt a marginal improvement with scores of 2 or 1. These results demonstrate a positive adoption of 5.0 technologies with a significant contribution to the sustainable optimization of operational processes, in line with the objectives of Green Lean Six Sigma.

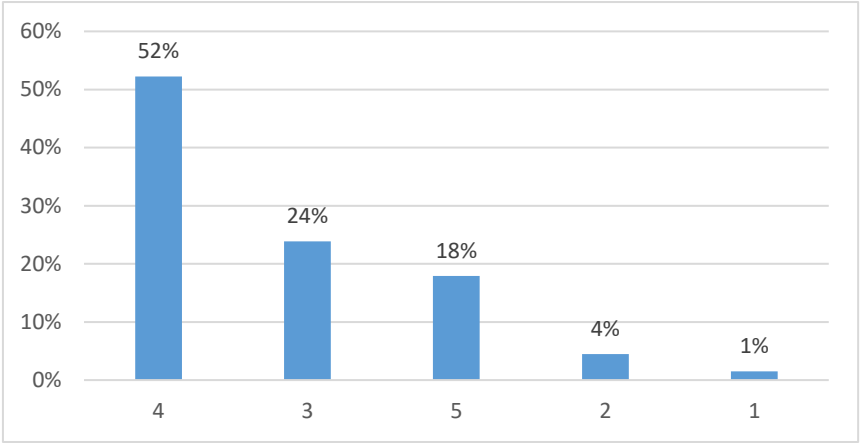

Figure 5: Impact assessment of technology 5.0 sustainable process optimization

The study found that Industry 5.0 technologies contribute to improving the sustainability of operational practices, which are essential to the Green Lean Six Sigma methodology. Figure 6 illustrates the key contributions of Industry 5.0 technologies to sustainable practices. Respondents identified four main areas where industry 5.0 technologies have had a significant positive impact: First, 60% of companies attest to a significant reduction in their carbon footprint, thanks to processes optimized by tools like AI and automation, aligning operational performance with the environmental goals of Green Lean Six Sigma. Secondly, the incorporation of sustainable materials in production processes is highlighted by 43% of respondents, reflecting a transition to responsible resource consumption practices, encouraged by technological advances that facilitate the choice of materials with a low ecological impact. Third, waste management is optimized for 52% of companies, illustrating how technology has enabled the reduction of waste production, in line with the resource-saving principles of Green Lean Six Sigma. Finally, 50% respondents indicate the adoption of energy-efficient technologies, highlighting the endeavor to reduce energy usage and encourage the adoption of clean energy sources, in line with the Green Lean Six Sigma commitment to energy efficiency and a reduction in greenhouse gas emissions. The results of the study highlight the significant impact of new technologies on the adoption of more sustainable practices within the companies surveyed. These innovative technologies are proving to be effective in enhancing energy efficiency, lowering greenhouse gas emissions, and promoting greener production.

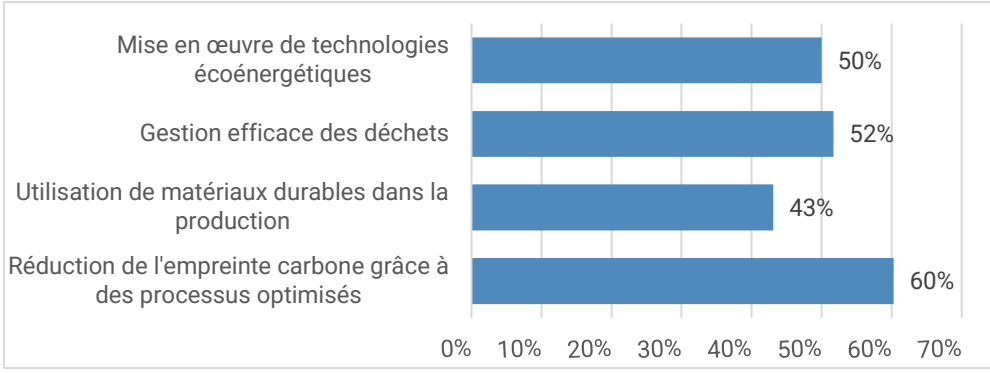

Figure 6: Contribution of 5.0 technologies to sustainable practices

The impact of emerging 5.0 technologies on business innovation has been evaluated in this study, with results revealing a positive trend, as shown in Figure 7 below. Most respondents (77%) attribute 5.0 technologies to a favorable role in stimulating innovation, with 38.5% of participants giving them a score of 4 and 7.7% a maximum score of 5. This appreciation suggests that technological advancements are not only adopted for their existing functionalities, but are also a catalyst for further innovation, prompting companies towards new ways of thinking and acting. However, a significant portion of the sample (38.5%) considers this stimulation to be at a moderate level, indicating a score of 3, which could reflect challenges in the adoption or integration of these technologies to generate tangible innovation. Finally, a minority of respondents (15.4%) express more skepticism, with scores of 1 and 2, highlighting that the benefits of new technologies are not uniformly felt across the business spectrum. These insights underscore the importance of a well-thought-out integration strategy for Industry 5.0 technologies to realize their full innovative potential.

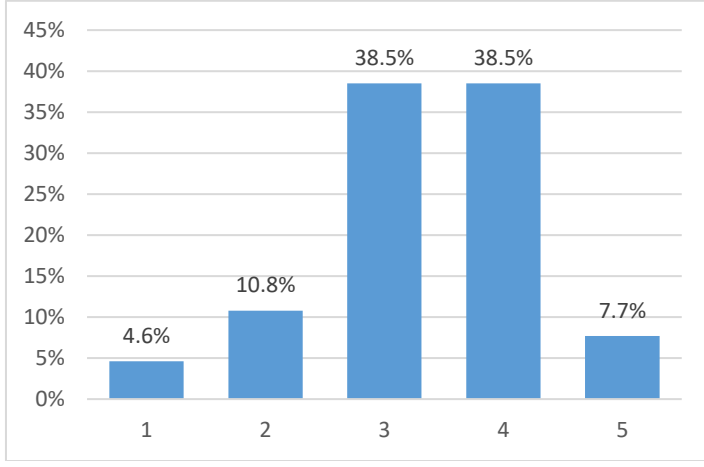

Figure 7: Impact of 5.0 technologies on Sustainable Innovation

The study also assessed the impact of 5.0 technologies on the environmental sustainability of operations, a pillar of Green Lean Six Sigma. Figure 8 illustrates the impact of 5.0 technologies on sustainable performance, as perceived by respondents. A considerable majority believe that technological innovation has had a positive effect. Indeed, 39% of respondents gave a score of 3 out of 5 to the impact of technologies, while 37% gave a score of 4, indicating that new technologies have contributed substantially to the sustainability of their operations. An additional 10% perceived this impact as very significant, with a score of 5. Despite this, a minority of 4% and 9% of respondents felt little or no impact, respectively, with scores of 1 and 2. These results reflect a positive overall trend and indicate the growing importance of investments in new technologies to improve the environmental performance of companies. While most respondents perceive a noticeable improvement in sustainability thanks to 5.0 technologies, there is potential for more extensive adoption and integration to maximize environmental benefits.

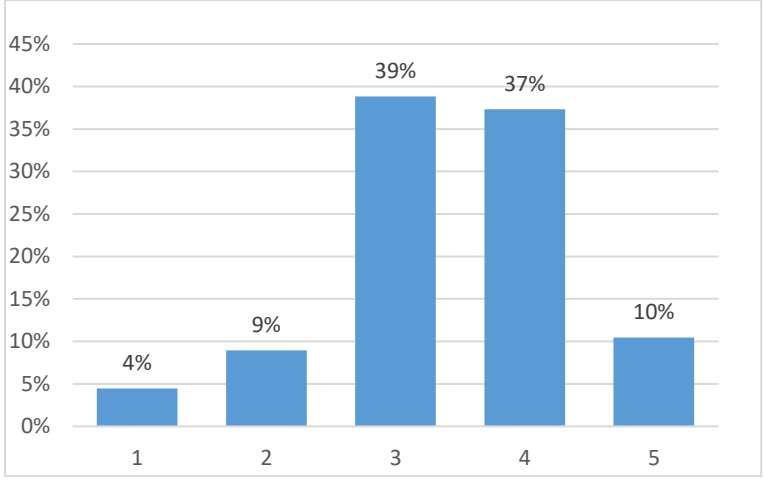

Figure 8: Impact of 5.0 technologies on sustainable performance

4. Discussion

The results of this study reveal a significant impact of Industry 5.0 technologies on corporate sustainability, demonstrating their ability to increase the effectiveness of Green Lean Six Sigma. The integration of tools such as real-time monitoring, intelligent automation, and predictive analytics marks a shift toward more efficient and sustainable operations, characterized by significant improvements in process control and evidence-based decision-making. These technologies appear to support Green Lean Six Sigma initiatives, providing ways to increase operational efficiency while improving environmental sustainability. Indeed, the data collected underscores the growing importance of these technologies in improving operational efficiency and sustainability. This effective synergy with Green Lean Six Sigma in process optimization illustrates a growing commitment of companies to environmentally friendly practices.

Sustainable innovation is another area where Industry 5.0 technologies have proven to be a strategic lever. By facilitating the development and integration of sustainable materials and more efficient waste management practices, companies are able to meet increased regulatory requirements and consumer expectations for environmentally friendly products and services. The variation in the perceived impact of 5.0 technologies raises questions about the barriers and facilitators of this adoption. Resistance to change, high upfront cost of implementation, and lack of technical skills are among the most significant barriers. A tailor-made support strategy is recommended to overcome these barriers and ensure a successful integration of 5.0 technologies.

Investment in continuous staff training is essential to fully exploit the potential of 5.0 technologies [54] and adhere to the principles of Green Lean Six Sigma. Organizations must cultivate a culture of continuous improvement and learning that supports sustainable innovation and growth. The successful implementation of 5.0 technologies and Green Lean Six Sigma principles often requires close collaboration between different departments within a company, as well as with suppliers, customers and industrial partners. Sharing knowledge and best practices can accelerate the adoption of these technologies and multiply their positive impact on sustainability [55].

This study explored the intersections of Industry 5.0 technologies and Green Lean Six Sigma, providing a unique perspective compared to previous work. Indeed, previous research has mainly focused on the interaction between Lean Six Sigma and Industry 5.0, or between Green Lean Six Sigma and Industry 4.0. However, our study stands out by specifically addressing Green Lean Six Sigma in the context of Industry 5.0. Previous studies, such as those by Rahardjo and Wang, as well as Rahardjo, Wang, Lo, and Chu, have proposed new sustainable innovation frameworks based on Lean Six Sigma tools and Industry 5.0 technologies to achieve process excellence [1-2]. This research focused on the overall impact of Lean Six Sigma combined with Industry 5.0 technologies to reduce process variations and achieve iterative improvement [1-2]. Instead, this study broadens this perspective by demonstrating how these technologies can specifically improve sustainability within a Green Lean Six Sigma framework. It suggests that the integration of these technologies into GLSS approaches could become a new paradigm for sustainable operational excellence.

The results of this study are a continuation of previous research while making a unique contribution by examining the specific interaction between 5.0 technologies and Green Lean six sigma practices, an area that is still little explored. This study highlights the significant impact of Industry 5.0 technologies on improving Green Lean Six Sigma practices. The synergy between these technologies and Green Lean Six Sigma practices offers the opportunity to improve operational excellence while strengthening the commitment to sustainability. Thus, this work contributes to enriching the existing literature by highlighting the combined benefits of Industry 5.0 and Green Lean Six Sigma technologies for sustainability, providing a practical framework for companies seeking to align their operational strategies with environmental objectives.

Even though this study offers important insights into the potential synergies between Industry 5.0 technologies and Green Lean Six Sigma practices. The relatively short study period does not allow for the assessment of the long-term effects of 5.0 technologies, nor for measuring the

evolution of environmental and operational performance over time. In addition, the variability in technology adoption across sectors underscores the need for more specific future research.

Future research should explore these synergies over a longer period of time to better understand the long-term impact of Industry 5.0 technologies. Longitudinal studies and in-depth case analyses in different sectors would capture the complex dynamics and better assess the benefits and challenges of integrating these technologies. In addition, the impact of 5.0 technologies on other aspects of sustainability, such as corporate social responsibility, is worth studying to offer a more holistic view of their potential.

In summary, the findings of this study underscore the significance of Industry 5.0 technologies for companies wishing to increase the effectiveness of their Green Lean Six Sigma approach. The judicious adoption and adaptation of these technologies, coupled with a culture of continuous improvement and sustainability, can significantly improve operational performance and also contribute substantially to the reduction of the environmental impact of industrial activities.

5. Conclusion

This study analyses the impact of the adoption of Industry 5.0 technologies by companies in various sectors on improving their sustainability and operational efficiency, in line with the principles of Green Lean Six Sigma. Promising areas of synergy between Green Lean Six Sigma and Industry 5.0 technologies have been identified.

Sustainable process optimization is enhanced by the integration of emerging technologies, enabling more efficient resource management and waste reduction. Energy efficiency and emission reduction are significantly improved through smart energy management systems, helping to minimize the carbon footprint of industrial operations. Sustainable customization is achieved through the adaptability of Industry 5.0 technologies, offering tailor-made production that respects the principles of the circular economy. In addition, data analytics for sustainability plays a crucial role in optimizing environmental and operational performance, enabling decision-making based on accurate, real-time data. Sustainable innovation is encouraged by these advanced technologies, stimulating the development of green products and services that meet consumer needs while promoting environmental preservation. Together, these areas of synergy demonstrate how the integration of Industry 5.0 technologies with Green Lean Six Sigma can lead to manufacturing practices that optimize operational efficiency and also support the commitment to a sustainable future.

The combination of Industry 5.0 technologies with Green Lean Six Sigma practices presents significant opportunities for research and improvement of operations. To get the most out of this combination, it's critical for organizations to take an integrated approach that considers technology, people, and processes together. This approach must also recognize that the influence of these technologies extends far beyond improving operational efficiency, also contributing to the broader goal of environmental and social sustainability. To maximize the effectiveness of the integration of 5.0 technologies, it is essential that companies invest in the training of their staff

to develop the technical skills necessary to fully exploit the potential of these technologies and support the implementation of Green Lean Six Sigma initiatives.

The study encourages companies to rethink their business models by integrating sustainable practices, supported by Industry 5.0 technologies. Companies can use the synergies between Industry 5.0 and Green Lean Six Sigma to more easily anticipate and comply with environmental regulations. Advanced technologies make it possible to monitor and report sustainability indicators more effectively, facilitating compliance and reducing the risk of sanctions. These practical implications provide a framework for companies looking to modernize their operations while meeting the growing challenges of sustainability and efficiency.

The study is carried out over a relatively short period of time, which does not allow for the assessment of the long-term effects of 5.0 technologies, nor for measuring the evolution of environmental and operational performance over time. This restricts the ability to draw direct causal connections between the applications of Industry 5.0 technologies and the improvement of environmental performance, thus limiting the understanding of the complex dynamics between Industry 5.0 technologies and Green Lean Six Sigma practices. In addition, the integration of Industry 5.0 technologies into Green Lean Six Sigma practices is based on the assumption that companies have the resources to adopt these technologies. These limitations suggest that future research could include longitudinal studies that track the implementation and impact of Industry 5.0 technologies on GLSS over an extended period of time. This would provide a better understanding of the long-term effects of these technologies on operational excellence and sustainability and identify potential challenges or barriers that may arise as technologies and organizational practices evolve. It could also include studies on the financial, technical and human resource challenges that organizations face and the development of strategies to overcome these obstacles. Future studies could focus on identifying best practices for integrating 5.0 technologies into Green Lean Six Sigma programs and assessing their long-term impact on business performance and the environment. In addition, exploring the impact of 5.0 technologies on other aspects of sustainability, such as corporate social responsibility, could offer interesting insights.

What are the limitations of this study?

Further scope for future research?

Any practical implications?

Please make sure that references are all in English with complete details including DOI links.

Ethical considerations*

This research involved a literature review and a survey of industry practices. No human participants or animals were involved in experimental procedures, and therefore, no ethical approval was required. Participants were informed about the nature of the study, what was expected of them before consenting to participate.

Data availability*

The data that support the findings of this study are available from the corresponding author upon request.

Reporting guidelines*

This article adheres to general reporting guidelines to ensure transparency and reproducibility of the research. We have ensured that all methods and results are described comprehensively to allow for replication of the study

Competing interests*

The authors declare no competing interests.

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