# Integrating Lean Six Sigma and Environmental Sustainability: A Composite Metrics Framework for Smart Manufacturing

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***Abstract***
*This paper examines how operational excellence can be aligned with environmental sustainability in contemporary manufacturing by integrating Lean Six Sigma and Industry 4.0 technologies. It addresses gaps in existing performance measurement frameworks, which often overlook environmental impacts and the role of digital tools in supporting sustainable development. A systematic review of 127 peer-reviewed articles is conducted to analyze how traditional process improvement methods, sustainability metrics, and technological tools are currently combined in practice. The review shows that most Lean Six Sigma implementations still rely on traditional measures such as defect rates, cycle times, and cost savings, with relatively few organizations using integrated indicators that reflect resource use, carbon emissions, or digital transformation. Building on these findings, the paper proposes a multi-level composite metrics framework that links conventional efficiency measures with environmental and technology-enabled indicators. The framework and associated composite metrics are intended to support better decision-making by helping manufacturers assess operational quality, resource efficiency, and sustainability performance in a more integrated way and to provide a clear basis for future empirical studies and practical applications in sustainable smart manufacturing.*

***Keywords***
*Environmental Sustainability; Environmental Metrics; Industrial Sustainability; Industry 4.0; Operational Performance.*

## Introduction

Current industrial practices are undergoing rapid, sometimes uneven, transformation as sustainable manufacturing, Lean Six Sigma, and Industry 4.0 tools are introduced into existing production systems. In many sectors, these approaches coexist in factories and supply chains rather than being developed as separate improvement programs. Lean Six Sigma has long been used to cut defects and improve process efficiency, but the indicators traditionally used to monitor its impact say relatively little about environmental consequences or the degree of digitalization in operations. Common measures such as defect counts, cycle times, or efficiency rates rarely reflect differences in energy use or emissions profiles and usually ignore how digital technologies reshape performance (Albliwi et al., 2015). At the same time, manufacturers are facing growing scrutiny from regulatory bodies, customers, and other influential industry stakeholders, who are increasingly looking for evidence of progress not only in terms of cost savings and product quality, but also in measurable environmental responsibility.

Digital tools from Industry 4.0, including the Internet of Things, artificial intelligence, robotics, and advanced analytics, are fundamentally reshaping how businesses manage and improve their manufacturing processes. These tools facilitate the ongoing acquisition of data from machinery and systems, thereby supporting real-time monitoring and enabling predictive maintenance strategies, alongside more autonomous decision-making processes (Lasi et al., 2014; Xu et al., 2018). Consequently, these capabilities offer a way to re-evaluate performance measurement across operational, environmental, and digital areas, challenging the traditional separation of these domains. Despite the considerable body of research addressing environmental pressures and technological advancements, there is a limited number of studies investigating the potential for reconfiguring established Lean Six Sigma frameworks to integrate circular economy principles, sustainability goals, and Industry 4.0 capabilities in a unified manner (Cherrafi et al., 2016; Farias et al., 2019). Current research on green or sustainable Lean Six Sigma frequently remains at the level of broad models or isolated case studies, offering limited practical direction for practitioners seeking to redesign performance metrics. This paper addresses that gap by analyzing the main challenges and integration strategies reported in both academic and industry sources, and by outlining a way to connect Lean Six Sigma indicators with sustainability and digitalization metrics in Industry 4.0 settings. The primary focus is on reframing performance measurement to make the tensions and synergies between efficiency, environmental performance, and digital capabilities visible and manageable.

Building on current research in sustainable and smart performance measurement, this study proposes a set of key performance indicators and a composite index to more accurately reflect performance in contemporary manufacturing environments. This paper is structured as follows: Section 2 presents a review of the relevant literature on Lean Six Sigma, sustainability, and Industry 4.0; Section 3 describes the methodological approach; Section 4 discusses the results and synthesizes the key findings; and Section 5 outlines the main conclusions and implications for future research and industrial practice.

## Literature review

Lean Six Sigma (LSS) comprises two distinct methodologies: Lean Manufacturing and Six Sigma. LSS is an approach that combines Lean Manufacturing's waste streamlining and Six Sigma's process implementation capability, using data science to sustain low defect rates in production (Antony et al., 2019). Lean Manufacturing originated in 1950 with the development of several pull systems and just-in-time production to eliminate waste in manufacturing; Six Sigma began in the 1980s at Motorola as a set of statistical methods to detect and reduce defect rates to near zero. Together, these approaches to process integration have led to significant improvements in process operations and product output (Antony et al., 2019). \

ultiple studies have investigated the impacts of LSS. For example, a review methodology of 56 case studies found that Lean Six Sigma projects achieved a reduction between 15-50% in cycle time, a reduction of the costs (10-30%), and a reduction of defects (50-90%) (Laureani & Antony, 2019). Recent examples include Thomas et al. (2014), who studied 96 manufacturing companies that had implemented LSS programs and found a 50% reduction in inventory levels, a 60% reduction in lead times, and a 25% increase in productivity. Other findings include a 30% reduction in assembly-line errors, a 22% increase in first-time production, and total company savings in the range of USD 400-500 million (Garza-Reyes, 2015).

Despite the above findings and the operational improvements achieved, it is shown that traditional LSS implementation and practical applications do not normally attend to environmental sustainability, among other considerations. A review of the literature showed that of the above studies, only about 23% included environmental considerations within a lean framework (Cherrafi et al., 2016). LSS tools provided recognition of impacts, but few, such as value stream mapping and 5S, address environmental concerns in practice. 14% reported positive environmental effects, compared with 87% reporting economic benefits (Farias et al., 2019). In most cases, there is an acknowledgment that environmental performance associated with business process improvements is a secondary consideration to the business or nominal cost reductions (Verrier et al., 2016), and less than 8% LSS projects surveyed reported measuring environmental performance explicitly, indicating a clear neglect/overlooking of ecological impact/s associated with process change LSS (Chugani et al., 2017).

Industry 4.0 is emerging with new proactive technologies associated with cyber-physical systems, the Internet of Things (IoT - systems monitoring and reporting), cloud computing, and artificial intelligence (Lasi et al., 2014). These elements are regarded as intelligent manufacturing systems, smart factories, industrial internet, and cloud manufacturing (Xu et al., 2018). Industry 4.0 is increasing. One noteworthy report documented 92 organizations that had begun implementing the technology, with a 300% increase from 2015-2018 (Frank et al., 2019). The rapid benefits from studies demonstrated a 35% reduction in planning errors and a 28% reduction in resource usage (Zhong et al., 2017), as well as improved equipment effectiveness and, in some cases, a 50% reduction in machine downtime (Basak et al., 2022). However, many organizations recognized that there are significant challenges regarding the integration of legacy systems and ever-present data security issues associated with data protection (Xu & Duan, 2018).

***Manufacturing sustainability initiatives***

Green manufacturing strategies aim to generate economic value while reducing environmental impact through industrial systems (Deif, 2011). Green manufacturing interventions primarily focus on process modifications and improvements, product quality, and supply chain management (Deif, 2011). The evidence is accumulating that green-related reductions in resource consumption are substantial, and it has been reported that decreased consumption by manufacturing organizations included 18% in energy use, 24% in water use, and 27% in solid waste (Govindan et al., 2015). In a review of 63 case studies, 45% reported reduced use of toxic materials, and 35% of products showed increased recyclability (Jawahir & Bradley, 2016). Carbon footprint reduction is prioritized, comprising three main strategies: energy efficiency improvements, renewable energy implementation, and process-based carbon optimization, which contribute 22%, 35%, and 18% reductions, respectively (Zhang et al., 2025).

Life cycle assessment (LCA), regardless of the organization, offers 2.5 times more opportunities for carbon reduction than facility-focused emissions (Hellweg & Milà i Canals, 2014). Improving energy efficiency is essential for sustainability, where it is shown that annual reductions in energy intensity occurred from 2–4%; also, energy management systems have produced energy savings in the range of 10–30% reductions, particularly in energy-intensive industries (Boyd & Curtis, 2014; Thollander & Ottosson, 2010). Technological advances, including motors and heat recovery systems, have enabled energy savings of 20-45% (Bunse et al., 2011). Despite these incremental shifts, the alignment of sustainability objectives with Lean Six Sigma objectives had limited success; of these initiatives, a mere 15% included ecological initiatives, and there was an absence of any formal alignment between Lean Six Sigma and environmental systems (Cherrafi et al., 2018; Garza-Reyes et al., 2018).

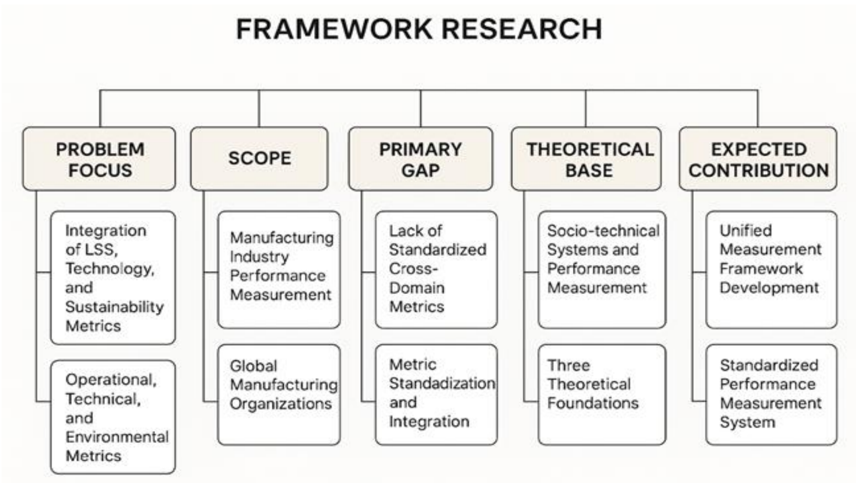


**Figure 1. Framework research**
Source: Authors' research results

Organisational silos continue to impact sustainability, and most companies tend to separate these management functions into different silos (Sony & Naik, 2019). Industry 4.0, which contains opportunities to enhance sustainability in manufacturing, like Industry 2.0 or 3.0, is stunted by many common modal barriers, including technical and skills gaps, and 78% of small and medium enterprises (SMEs) cited costs as a significant barrier, while 82% reported a significant skills gap in their workforce (Müller et al., 2018; Karre et al., 2017). A significant research gap remains, as there are still no robust models that support the real-time integration of data-driven sustainability indicators with advanced manufacturing systems (see Figure 1).

## Methodology

This review highlights a clear gap in the literature on sustainability, new technologies, and Lean Six Sigma (LSS), particularly regarding integrated approaches that connect these domains. LSS, by its very nature, focuses on process optimization and is based on a rapid, data-driven methodology; however, recent literature and practices are still developing and struggling to integrate environmental sustainability and the potential of Industry 4.0. As shown in Figure 2, advanced models that leverage digital transformation, real-time data, and analytics are needed to improve operational performance and environmental sustainability in manufacturing. This approach systematically reviews the integration and convergence of LSS, sustainability, and digitalization using a systematic review of recent, peer-reviewed literature.

The lack of synergy in Figure 4 represents a gap in these categories, and it is necessary to develop a holistic framework that delivers operational excellence, a construct committed to continuous improvement, value, and adaptation to customer and environmental requirements for the digitized user. Environmental sustainability is, then, a central construct to the progressive sustainability context of digital transformation, where the interconnectedness of efficiency, digital technology, and the environment becomes essential.

A systematic review was conducted using 127 peer-reviewed articles identified through selective searches of the databases Web of Science, Scopus, IEEE Xplore, and ScienceDirect. Articles were included based on LSS implementation and performance indicators, while theoretical literature based on non-data sources was excluded. 78% (99 of 127) of the reviewed articles used traditional performance indicators, cycle time, defect rates, cost, and resource use while also failing to leverage overlaps in environmental or technological improvements (Figure 3).

The term "traditional performance indicators", as designated here, represents the performance measurement processes that are historically applicable metrics that did not capture emissions, resource depletion, and the disruption of real-time, technology-enabled objective assessment. Only 22% (28 of 127 articles) used an "integrated" approach associated with IoT, real-time monitoring, eco-efficiency, and sustainability-related performance indicators such as carbon and energy footprint (see Figure 4).

It is worthwhile to consider the distinction between "integrated performance indicators" and "traditional performance indicators": the former are associated with digital and sustainability performance indicators, while the latter are associated with legacy behavior and financial performance indicators. The established historical approaches illustrated in Figure 3, which account for 78% of traditional indicators, reveal a significant gap in our understanding of composite performance indicators that simultaneously capture technological advancements, process improvements, and environmental sustainability.

This literature-based approach provided a quantitative rationale for our understanding of current assessment limitations. It validated the composite framework as a suitable basis for academic studies and for use in advanced manufacturing environments that require rigorous, data-driven support for operational decision-making.

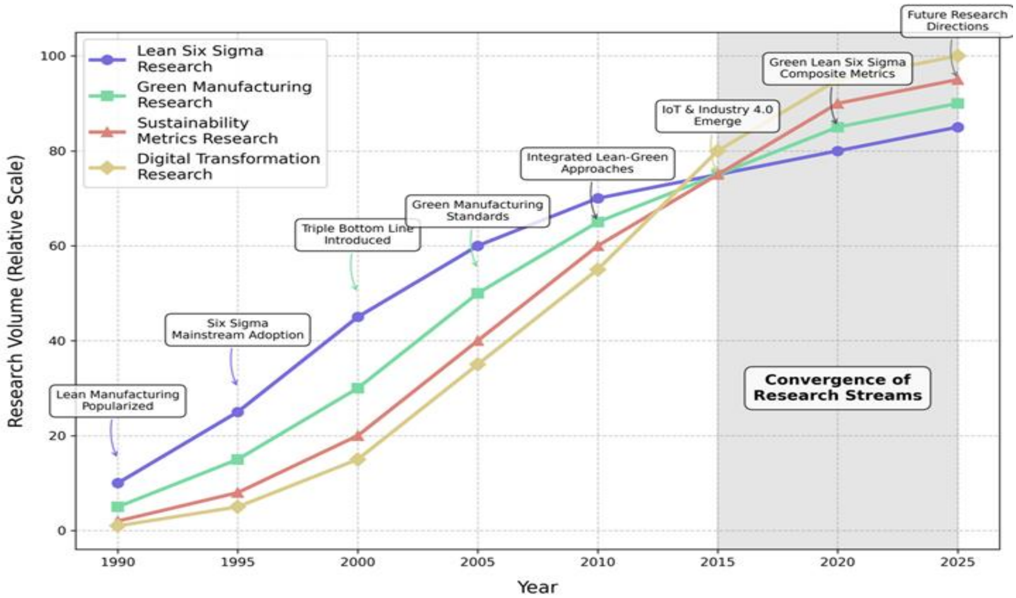


**Figure 2. Evolution and convergence of research streams**
Source: Authors' own research results

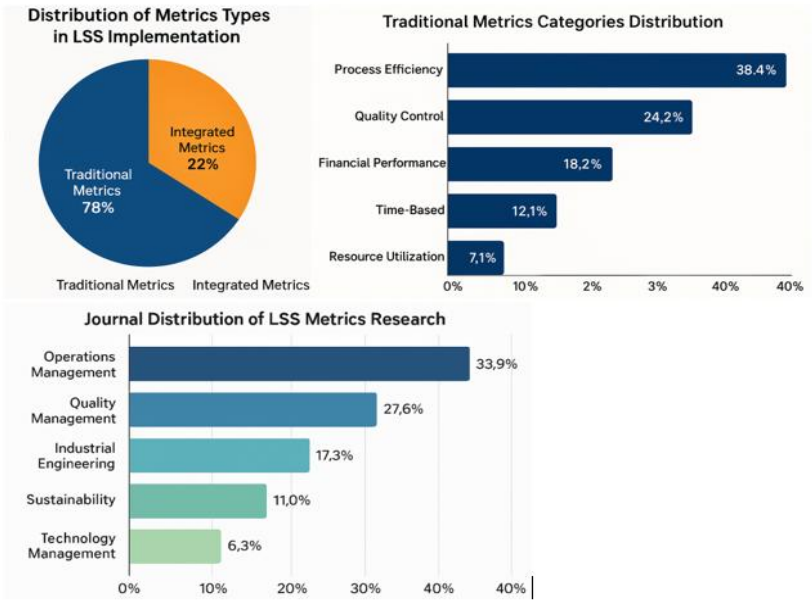


**Figure 3. Overview of the landscape of LSS metrics research**
Source: Authors' research results

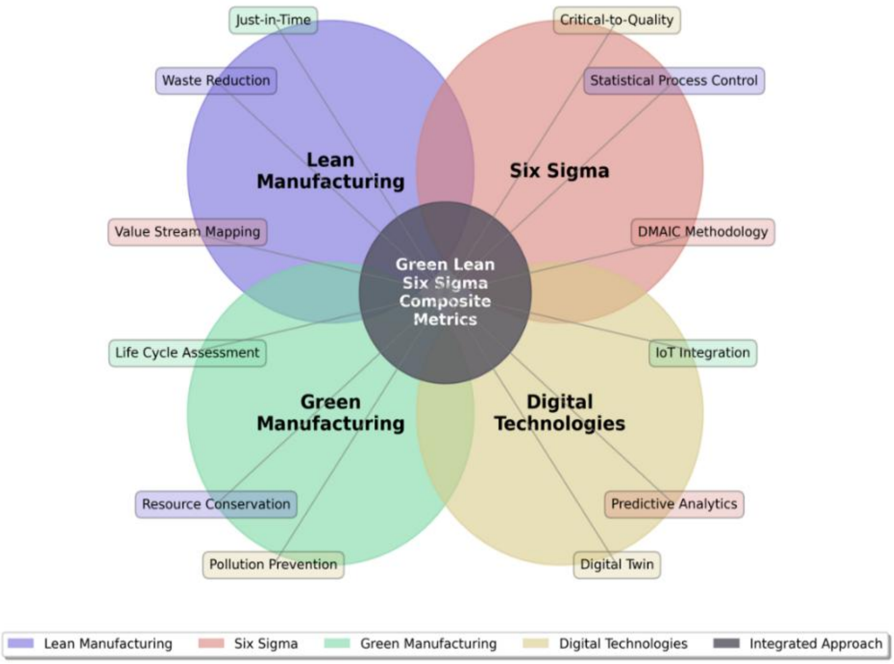


**Figure 4. Conceptual Framework of Green Lean Six Sigma Composite Metrics**
Source: Authors' own research results

## Results and discussion

The extensive review assessed 127 peer-reviewed articles in the Lean Six Sigma literature, indicating that approximately 78.3% of implementations use traditional performance metrics. The review further indicates that the typical organization adopting Lean Six Sigma focuses on traditional metrics (e.g., cycle time, defect rates, cost savings), generally ignoring key metrics related to economic resources and additional co-benefits arising from technological synergies. Furthermore, traditional metrics are insufficient indicators of resource depletion, carbon emissions, and digital technologies (i.e., data-related and real-time), thereby reducing a firm's ability to reflect a comprehensive range of operational performance in an environment where sustainability and technology are critical.

Increased reliance on traditional metrics likely derives from a historical emphasis on operational optimization and defect reduction, without asking too much of the broader implications of manufacturing processes regarding digital transformation and environmental sustainability. Awareness of this difference necessitates revising Lean Six Sigma frameworks to include hybrid metrics that assess both process improvement and the value-added aspects of measurement in Green Lean Six Sigma. The focus will be on composite indices or key performance indicators in Table 1 that stimulate better collaborative, coordinated, and aligned energy use, environmental impact, and technological acceptance.

**Table 1. Composite indices or key performance indicators**

| *No.* | *Traditional LSS Metrics* | *Environmental Metrics* | *Technology-Enabled Metrics* |
|---|---|---|---|
| **1** | Defect Rate (DPMO) | Carbon Footprint | Digital Process Efficiency |
| **2** | Process Cycle Time | Energy Consumption | Automation Impact Index |
| **3** | First Pass Yield | Water Usage | IoT Data Utilization Rate |
| **4** | Overall Equipment Effectiveness (OEE) | Waste Generation | AI-Driven Optimization Score |
| **5** | Takt Time | Renewable Energy Utilization | Predictive Maintenance Effectiveness |
| **6** | Lead Time | Material Efficiency | Digital Twin Accuracy |
| **7** | Value-Added Ratio | Emissions Reduction | Real-time Monitoring Coverage |
| **8** | Process Capability (Cp/Cpk) | Resource Depletion Impact | Data-Driven Decision Rate |
| **9** | Rolled Throughput Yield (RTY) | Ecological Footprint | Technology Integration Level |

Source: Authors' research results

The next step is to conduct a more in-depth investigation of possible composite metrics that could close this gap. Proposed Composite Metrics for Green Lean Six Sigma, see Table 2.

**Table 2. Theoretical foundation of Green Lean Six Sigma Composite Metrics**

| *No.* | *Name* | *Description* | *Components* | *Application* |
|---|---|---|---|---|
| 1 | Green Process Efficiency Index (GPEI) | Measures process efficiency while accounting for energy usage and digital optimization | Process Cycle Time, Energy Consumption, Digital Process Efficiency | Manufacturing processes, logistics operations |
| 2 | Sustainable Value Stream Ratio (SVSR) | Extends traditional value stream mapping to include waste reduction and smart resource allocation | Value-Added Ratio, Waste Generation, Smart Resource Allocation | Value stream mapping, process improvement |
| 3 | Carbon-Adjusted OEE (CA-OEE) | Adjusts traditional OEE by factoring in carbon emissions and IoT-enabled optimizations | Overall Equipment Effectiveness, Carbon Footprint, IoT Data Utilization | Equipment performance evaluation, sustainability reporting |
| 4 | Predictive Environmental Quality Index (PEQI) | Combines quality metrics with emissions reduction and predictive maintenance | First Pass Yield, Emissions Reduction, Predictive Maintenance Effectiveness | Quality management, environmental compliance |
| 5 | Resource-Efficient Capability Index (RECI) | Extends process capability to account for material efficiency and digital twin simulations | Process Capability (Cp/Cpk), Material Efficiency, Digital Twin Accuracy | Process design, material optimization |
| 6 | Total Environmental Impact Cost (TEIC) | Comprehensive cost metric that includes quality costs, environmental impact, and technology ROI | Cost of Poor Quality, Ecological Footprint, Technology Integration Level | Financial analysis, investment decisions |

Source: Authors' research results

To advance sustainable operational excellence, organizations are increasingly adopting composite metrics that blend traditional Lean Six Sigma indicators with environmental and digital dimensions. These metrics are designed to provide a holistic view of process performance, resource efficiency, and environmental impact. Below, Table 3 presents our findings on the key composite metrics, their formulas, theoretical underpinnings, and validation methods, followed by Figure 4 for clarity.

**Table 3. Composite Sustainability Metrics Framework**

| **Base Formula** | | |
|---|---|---|
| Metric Name | **Base Formula** | |
| Green Process Efficiency Index (GPEI) | Traditional PCE = Value Added Time / Total Time | |
| Sustainable Value Stream Ratio (SVSR) | Traditional VSR = Value Added Time / Lead Time | |
| Carbon-Adjusted OEE (CA-OEE) | Traditional OEE = Availability × Performance × Quality | |
| Predictive Environmental Quality Index (PEQI) | Traditional Quality Index = Actual Quality / Target Quality | |
| Resource-Efficient Capability Index (RECI) | Traditional Cpk = min((USL-μ)/3σ, (μ-LSL)/3σ) | |
| Total Environmental Impact Cost (TEIC) | Traditional Cost = Σ(Process Costs) | |
| **Enviromental Extension and Final Formula** | | |
| **Metric Name** | **Environmental Extension** | **Final Composite Formula** |
| Green Process Efficiency Index (GPEI) | Environmental Waste Factor (EWF) = Σ(Environmental Impacts)/Max Impact | GPEI = (Value Added Time / Total Time) × (1 - EWF) |
| Sustainable Value Stream Ratio (SVSR) | Sustainable Value Factor (SVF) = Green Activities/Total Activities | SVSR = (Value Added Time × SVF) / Lead Time |
| Carbon-Adjusted OEE (CA-OEE) | Carbon Impact Factor (CIF) = CO2e/Baseline CO2e | CA-OEE = OEE × (1 - CIF) |
| Predictive Environmental Quality Index (PEQI) | Environmental KPI Weight (EKW) = Σ(Impact Weights × Measurements) | PEQI = Σ(EKW × Predictive Factors) |
| Resource-Efficient Capability Index (RECI) | Resource Efficiency Factor (REF) = Resource Usage/Optimal Usage | RECI = Cpk × REF × Sustainability Index |
| Total Environmental Impact Cost (TEIC) | Environmental Cost Factor (ECF) = Σ(Environmental Impact Costs) | TEIC = Σ(Process Costs + ECF) |
| **Metric Composite Description** | | |
| **Metric Name** | **Description** | |
| Green Process Efficiency Index (GPEI) | Measures process efficiency while accounting for environmental impact and green waste reduction | |
| Sustainable Value Stream Ratio (SVSR) | Evaluates the sustainability of value streams by incorporating environmental considerations | |
| Carbon-Adjusted OEE (CA-OEE) | Extends traditional OEE by including carbon footprint and environmental performance | |
| Predictive Environmental Quality Index (PEQI) | Predicts environmental quality using advanced analytics and real-time monitoring | |
| Resource-Efficient Capability Index (RECI) | Assesses resource utilization, efficiency, and process capability with a sustainability focus | |
| Total Environmental Impact Cost (TEIC) | Quantifies total environmental impact in monetary terms across the organization | |

| Implementation and Digital Integration | | |
|---|---|---|
| **Metric Name** | **Implementation Level** | **Digital Integration** |
| Green Process Efficiency Index (GPEI) | Process Level | IoT sensors, Real-time monitoring |
| Sustainable Value Stream Ratio (SVSR) | Value Stream Level | Digital value stream mapping |
| Carbon-Adjusted OEE (CA-OEE) | Equipment Level | Smart equipment monitoring, Carbon tracking |
| Predictive Environmental Quality Index (PEQI) | Plant Level | AI/ML predictions, Sensor networks |
| Resource-Efficient Capability Index (RECI) | Process/Product Level | Digital twin, Process monitoring |
| Total Environmental Impact Cost (TEIC) | Organization Level | Enterprise systems integration |
| **Sustainability and Benefits** | | |
| **Metric Name** | **Sustainability Aspects** | **Key Benefits** |
| Green Process Efficiency Index (GPEI) | Resource usage, Waste reduction, Energy efficiency | Balances efficiency with environmental impact |
| Sustainable Value Stream Ratio (SVSR) | Environmental value add, Waste elimination | Optimizes sustainable value creation |
| Carbon-Adjusted OEE (CA-OEE) | Carbon emissions, Energy consumption | Links equipment performance to environmental goals |
| Predictive Environmental Quality Index (PEQI) | Environmental compliance, Pollution prevention | Enables proactive environmental management |
| Resource-Efficient Capability Index (RECI) | Resource optimization, Sustainable capability | Ensures sustainable process capability |
| Total Environmental Impact Cost (TEIC) | Environmental cost accounting, Impact assessment | Provides financial visibility of environmental impact |

Source: Authors' research results

***The purpose of the summary table***

Understanding sustainability in the integration of composite metrics differs from assessing performance by examining metrics in isolation, as it demonstrates how processes impact efficiency, quality, technological advancement, and environmental readiness. Looking through the lens of composite metrics helps organizations understand how to make informed decisions based on sustainable and operational objectives.

The organization can identify options that align with its sustainable and operational objectives by integrating composite metrics into its *decision-making process*. The *benchmarking metric* hierarchy enables organizations to evaluate their performance against industry standards and best-in-class practices for environmental performance and Lean Six Sigma.

The *composite sustainability metrics* framework is a comprehensive integration of environmental concerns into the assessment of operational performance. Each of the five unique hierarchical levels – process, value stream, equipment, plant, and organizational – has specific metrics designed to provide insight into specific elements of sustainable operations. The Green Process Efficiency Index (GPEI) and Resource-Efficient Capability Index (RECI) integrate environmental impact considerations into normal efficiency assessments at the process level. The Sustainable Value Stream Ratio (SVSR) uses environmental footprint considerations from traditional Value Stream Mapping at the value stream level. The Carbon-Adjusted Overall Equipment Effectiveness (CA-OEE) is a new equipment-level metric that accounts for a carbon footprint when calculating the traditional OEE. The Total Environmental Impact Cost (TEIC) provides an organizational measure for quantifying environmental impact costs and using the Predictive Environmental Quality Index (PEQI) metric at the plant level to generate analytics from multiple models used to predict environmental quality.

The composite framework represents a strong digital integration strategy by employing IoT sensors, artificial intelligence, and digital twins to provide real-time context with advanced analytics for predictive capability. Overall, the composite metrics framework presents a significant improvement in sustainable manufacturing standards by offering a holistic assessment of sustainable performance while continuing operational excellence.

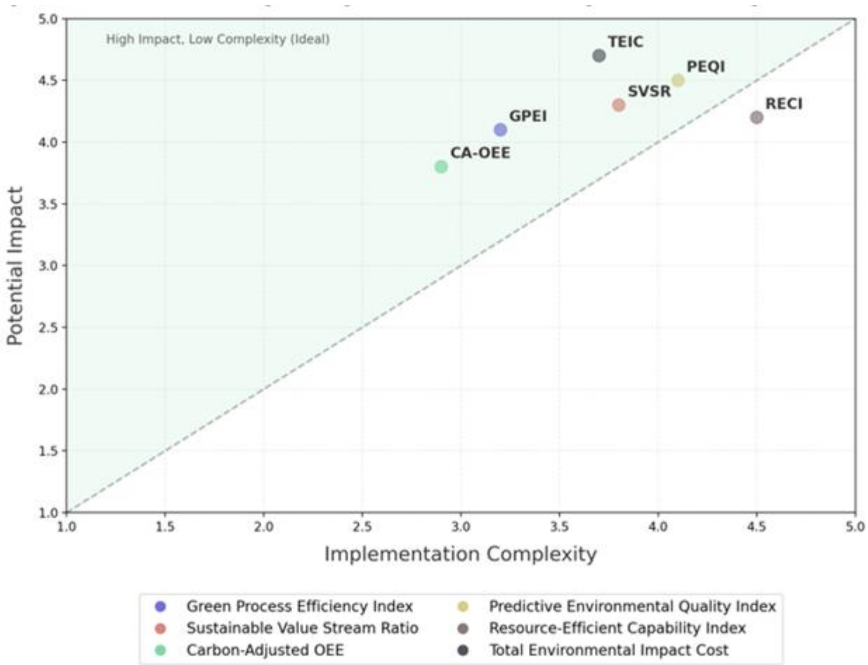


**Figure 6. Implementation Complexity vs. Potential Impact of Composite Metrics**
Source: Authors' research results

This scatter plot (Figure 6) shows each metric by implementation complexity and potential impact. With the "centered mass" of higher impact and lower complexity shaded in green, the visualization enables each metric to be identified on this physical map. The visual representation suggests that carbon-adjusted OEE (CA-OEE) receives the fairest scores for both implementation complexity and potential impact, and is the best candidate for initial adoption (considering a clinical trial approach). The total environmental impact cost metric (TEIC) provides the greatest potential impact, but the complexity is moderately challenging to implement if one were to explore the Green Lean Six Sigma Composite Metrics thoroughly. In combining traditional Lean Six Sigma with environmental aspects and technology enablers, six composite metrics were created. Each metric provides a more advanced approach to capturing operational excellence, integrated with sustainability and the context of digital transformation.

The proposed framework represents an important step forward in the extant literature by introducing a composite assessment framework for smart manufacturing performance. Unlike the current literature, which focuses solely on operational efficiency, sustainability, or digitalization as standalone dimensions, this research integrates traditional Lean Six Sigma metrics with sustainability and digital performance metrics in an operationally verified framework. Key innovations include composite indices, such as the Green Process Efficiency Index, or GPEI, and Carbon-Adjusted OEE, as well as definable formulae which facilitate joint evaluation of operational, environmental, and technological outcomes in relation to specific processes, equipment, value streams, and organizations. By facilitating benchmarking, optimization, and strategic decision-making for sustainable digital manufacturing, the work presented here addresses constraints of traditional Lean Six Sigma methods in the literature for Industry 4.0 (smart manufacturing).

## Conclusions

The rise of composite metrics in the GreenLean Six Sigma movement represents a real step forward in developing organizational performance measures that integrate traditional, environmental, and digital measures with operational performance and sustainability considerations. Composite metrics can help improve return on investment and serve as benchmarks for the interrelated complexities of performance in sustainability, environmental stewardship, and innovation. However, this advancement introduces complexity because it requires substantial foundational planning, the implementation of a data integration model, and the planning, design, and execution of the data integration process.

Composite metrics will remain a key component of manufacturing and other industries, as organizations aim to measure and continuously improve their operational performance in increasingly complex operating ecosystems. The more regular use of composite metrics will involve introducing real-time automation, efficient data integration, and practical design to improve the weighting and normalization of composite measures.

Future research and implementation by industry will lean toward the context in which they operate, and perhaps toward a more industry-specific approach, as no industry operates in the same way. This research also highlights the differences in testing the long-term impacts of composite measures on economic and sustainability performance. There will also be a need for further measures to standardize and customize composite metrics, as you suggested, between academics and business components to improve the accuracy and validity of enterprise performance measurement.

The incorporation of artificial intelligence and machine learning capabilities could most certainly improve the accuracy of composite metrics, which offer a measure of the current state, trends, and practical performance targets related to sustainability and high performance. To address some of the research implementation challenges identified across various disciplinary lenses, and now that technology has improved, composite metrics offer a focal point for establishing a key link between operational efficiency and environmental activities, which could help offer effective performance measurement and accountability for entering a new era of smart manufacturing. The use of composite metrics also offers an alternative strategic outcome and a way to optimize not only manufacturing performance but also the sustainability demands of the conditions presented in the contemporary digital marketplace. The only drawback is the absence of the substantive empirical tests needed to substantiate the generalizations in the framework presented. These findings represent a call to connect with industry and academics to better structure and scale composite metrics.

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