From Kaizen to Digital Continuous Improvement: Linking Lean Practices with Sustainability Metrics

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Abstract

Continuous Improvement (CI), grounded in Kaizen and Lean management, has traditionally focused on efficiency, quality, and cost performance. However, growing sustainability pressures require organizations to demonstrate measurable environmental, social, and economic outcomes supported by robust data and transparent metrics. This article introduces and empirically illustrates a Digital Continuous Improvement (DCI) framework that systematically integrates Lean practices with digitally enabled sustainability measurement systems. Drawing on multidisciplinary perspectives from operations management, industrial engineering, information systems, and sustainability science, the study develops a process-level measurement architecture that links Kaizen activities to sustainability Key Performance Indicators through technologies such as IoT sensors, Manufacturing Execution Systems, and analytics dashboards. Using a data-driven illustrative case, the results show that digitally supported Kaizen interventions can achieve substantial and simultaneous performance gains, including reductions in energy intensity (approximately 18–25%), material waste (20–30%), and process lead time (15–22%), alongside notable improvements in safety, ergonomics, and employee participation. Methodologically, the study advances Lean–sustainability research by enabling direct attribution of sustainability outcomes to specific improvement actions with the application of high-resolution operational data. Theoretically, it reframes Continuous Improvement as a digitally enabled sustainability capability, while practically offering a replicable KPI taxonomy and analytics workflow for organizations that are pursuing ESG-aligned operational excellence. The DCI framework provides a scalable foundation for future empirical research and industrial application in the context of Industry 4.0.

Keywords: *Digital continuous improvement; Kaizen; Lean management; Sustainability metrics; Industry 4.0; Operational excellence; ESG performance.*

INTRODUCTION

Continuous Improvement (CI), also known as Kaizen, has long been regarded as a cornerstone of operational excellence. With major objectives including enabling operators and managers to detect problems, ascertain improvement priorities, determine root cause of the problem, fix it, and then establish better ways to prevent such problems from reoccurring, Kaizen is defined as an increasingly common organizational improvement process that is aimed at work area transformation and employee development (Okpala *et al.*, 2024a; Onukwuli *et al.*, 2025). Rooted in the Kaizen philosophy, Lean management emphasizes incremental, employee-driven improvements that are aimed at waste elimination, quality enhancement, and processes stabilization (Ihueze and Okpala, 2014; Okpala *et al.*, 2020a). Over several decades, Lean and Kaizen practices have demonstrated robust performance benefits across manufacturing and service contexts, including improvements in productivity, cost efficiency, and delivery reliability (Liker, 2004; Chukwumuanya *et al.*, 2025). Yet, as global sustainability challenges intensify, organizations are increasingly expected to demonstrate not only operational efficiency, but also measurable environmental and social value creation.

The sustainability agenda has evolved beyond normative commitments and high-level reporting towards evidence-based performance management that is grounded in credible metrics. International frameworks such as the Global Reporting Initiative (GRI) and ISO 14031 emphasize the need for quantifiable, decision-relevant indicators of environmental and social performance. Despite this shift, many Continuous Improvement initiatives remain weakly connected to formal sustainability measurement systems. In practice, Lean improvements are often justified through economic outcomes alone, while sustainability indicators are monitored separately at the organizational level, thereby limiting learning, accountability, and scalability (Chiarini, 2014; Garza-Reyes *et al.*, 2018).

At the same time, digital transformation is reshaping how organizations generate, process, and use operational data. Technologies associated with Industry 4.0, including the Internet of Things (IoT), cyber-physical systems, Manufacturing Execution Systems (MES), and advanced analytics, enable real-time visibility of energy use, material flows, equipment performance, and human–machine interactions (Kagermann *et al.*, 2016). A growing body of research suggests that digitalization can complement Lean by increasing process transparency and responsiveness (Buer, Strandhagen, and Chan, 2018). However, empirical and conceptual work that is, integrating Lean, digital technologies, and sustainability metrics into a coherent improvement system, remains fragmented.

Existing “Lean and Green” studies provide important insights into how waste reduction may lead to environmental benefits, yet their findings are often context-specific and methodologically inconsistent due to divergent definitions of sustainability performance and limited use of high-resolution operational data (Martínez-Jurado and Moyano-Fuentes, 2014; Cherrafi *et al.*, 2016). Social sustainability dimensions like ergonomics, employee engagement, and skills development are even less systematically incorporated into Continuous Improvement research, despite their centrality to Kaizen philosophy (Liker and Hoseus, 2008). Consequently, there is a persistent gap between the micro-level logic of Kaizen activities and the macro-level sustainability outcomes that are demanded by regulators, investors, and society.

This article argues that bridging this gap requires reconceptualizing Continuous Improvement as a digitally enabled sustainability capability. The concept of Digital Continuous Improvement (DCI) was introduced, defined as the systematic integration of Lean practices with digitally captured environmental, social, and economic sustainability metrics in closed-loop improvement cycles. Rather than treating sustainability as a downstream reporting exercise, DCI embeds sustainability indicators directly into the design, execution, and evaluation of Kaizen initiatives. Digital infrastructures play a critical enabling role through the transformation of sustainability metrics into operational control variables that can be acted upon at the process and workstation levels.

The study addresses three interrelated research questions:

1) How can Lean and Kaizen practices be explicitly and systematically linked to measurable sustainability outcomes?
2) How do digital technologies enable this linkage by enhancing measurement resolution, feedback speed, and learning? and
3) What kind of Key Performance Indicator (KPI) architecture is required to align Continuous Improvement routines with environmental, social, and economic sustainability objectives?

By answering these questions, the article contributes to operations and sustainability literature in three ways. First, it extends Lean theory by positioning Continuous Improvement as a data-driven dynamic capability for sustainability. Second, it proposes a unified, multidimensional KPI taxonomy grounded in established sustainability standards yet operationalized through digital systems. Third, it provides data-driven evidence that illustrates how digitally supported Kaizen initiatives can deliver simultaneous environmental, economic, and social performance gains.

By integrating insights from operations management, information systems, industrial engineering, and sustainability science, this research responds to recent calls for more interdisciplinary and empirically grounded sustainability studies (Seuring and Gold, 2013; Govindan, 2020). In doing so, it lays a foundation for scalable, evidence-based Continuous Improvement systems which are capable of addressing contemporary sustainability challenges.

LITERATURE REVIEW

This study draws on and integrates four major bodies of literature:

a) Kaizen and Lean Continuous Improvement,
b) Lean–Sustainability integration,
c) sustainability measurement and performance metrics, and
d) digitalization and Industry 4.0–enabled operations.

Reviewing these streams jointly reveals persistent conceptual and methodological gaps that motivate the Digital Continuous Improvement (DCI) framework that is proposed in this article.

Kaizen and Lean Continuous Improvement

Kaizen, meaning “change for the better,” represents a people-centered philosophy of continuous, incremental improvement embedded in daily work routines (Imai, 1986; Okpala *et al.*, 2024b). Lean management operationalizes this philosophy through a structured set of principles and tools, including Value Stream Mapping (VSM), Just-in-Time (JIT), Total Productive Maintenance (TPM), 5S, and standard work, which are designed to eliminate non-value-adding activities (Womack and Jones, 1996; Ihueze and Okpala, 2012). Empirical research consistently links Lean implementation to improvements in cost, quality, flexibility, and delivery performance across different sectors (Shah and Ward, 2007; Fullerton *et al.*, 2014).

However, much of the Lean literature conceptualizes performance narrowly, emphasizing operational and financial outcomes while under-theorizing broader societal and environmental effects. Continuous Improvement initiatives are frequently evaluated using proxy measures such as productivity or lead time, which implicitly assume that efficiency gains translate into sustainability benefits. This assumption has been increasingly questioned, particularly in contexts where rebound effects or localized optimization may shift rather than eliminate environmental burdens (Piercy and Rich, 2015).

Lean and Sustainability: From "Lean and Green" to Integrated Perspectives

The intersection of Lean and sustainability has attracted growing scholarly attention under labels such as "Lean and Green" or "Sustainable Lean." Early studies argue that Lean's focus on waste elimination naturally aligns with environmental sustainability, particularly through reductions in material use, energy consumption, and emissions (King and Lenox, 2001; Ihueze *et al.*, 2011). Subsequent empirical research reports positive associations between Lean practices and environmental performance, especially in manufacturing settings (Chiarini, 2014; Okpala *et al.*, 2020b).

Despite these advances, findings remain mixed and difficult to generalize. Systematic reviews highlight significant heterogeneity in how sustainability is defined and measured, with many studies relying on perceptual or aggregated indicators rather than process-level data (Martínez-Jurado and Moyano-Fuentes, 2014; Cherrafi *et al.*, 2016). Moreover, the social dimension of sustainability, which is central to Kaizen's emphasis on respect for people, has received comparatively limited empirical attention. Issues such as ergonomics, employee learning, and participatory improvement are often discussed conceptually but rarely operationalized using robust metrics (Liker and Hoseus, 2008; Longoni *et al.*, 2014). These limitations suggest that Lean and sustainability have largely evolved as parallel rather than integrated performance systems, which has been constraining their combined impact.

Sustainability Measurement and Performance Metrics

A critical challenge in the operationalization of sustainability lies in measurement. International standards such as ISO 14031 and frameworks such as the Global Reporting Initiative (GRI) emphasize the need for consistent, comparable, and decision-relevant indicators across environmental, social, and economic dimensions. In practice, however, sustainability metrics are often collected at high levels of aggregation and used primarily for external reporting rather than internal operational control (Burritt and Schaltegger, 2010). Operations and supply chain scholars increasingly call for the linking of sustainability indicators to core process metrics in order to enable continuous improvement and learning (Neely *et al.*, 2005; Beske-Janssen *et al.*, 2015). Yet empirical studies integrating sustainability KPIs into day-to-day improvement routines remain scarce. This gap is particularly pronounced at the shop-floor level, where Kaizen activities take place but sustainability data are often unavailable or delayed.

Digitalization, Industry 4.0, and Data-Driven Improvement

Digital transformation offers new opportunities to overcome longstanding measurement and integration challenges. Industry 4.0 technologies like IoT sensors, cyber-physical systems, cloud-based analytics, and Manufacturing Execution Systems (MES) enable continuous, high-resolution monitoring of resource consumption, equipment performance, and human–machine interactions (Kagermann *et al.*, 2016). Recent studies suggest that digitalization can reinforce Lean principles through transparency enhancement, variability reduction, as well as faster feedback loops enhancement (Buer *et al.*, 2018; Sanders *et al.*, 2016).

Emerging research at the intersection of digitalization and sustainability indicates that data-driven approaches can support energy efficiency, predictive maintenance, and waste reduction (Müller *et al.*, 2018; Stock *et al.*, 2018). However, this literature often treats Lean and digitalization as complementary but separate initiatives. Few studies explicitly examine how digital technologies can embed sustainability metrics within Continuous Improvement cycles, nor do they provide empirically grounded KPI architectures that link Lean actions to sustainability outcomes.

Synthesis and Research Gap

Taken together, the literature reveals three persistent gaps. First, Lean and Kaizen research continues to privilege economic performance, with sustainability outcomes treated as secondary or indirect. Secondly, sustainability measurement systems remain weakly connected to operational improvement routines. Thirdly, while digital technologies offer unprecedented data capabilities, their role in systematically linking Continuous Improvement to sustainability performance remains under-theorized and under-tested. The ability to address these gaps requires an integrative perspective that reconceptualizes Continuous Improvement as a digitally enabled sustainability capability. The Digital Continuous Improvement (DCI) framework proposed in this study responds to this need by explicitly connecting Lean practices, digital infrastructures, and multidimensional sustainability metrics within closed-loop improvement systems. By doing so, it advances the literature towards more rigorous, data-driven, and actionable sustainability research.

CONCEPTUAL FRAMEWORK: DIGITAL CONTINUOUS IMPROVEMENT (DCI)

Rationale for a Digital Continuous Improvement Framework

Continuous Improvement has traditionally relied on periodic problem identification, manual data collection, and experience-based decision-making. While effective in stable environments, these approaches struggle to capture complex sustainability impacts that unfold across time, processes, and organizational boundaries. Sustainability performance, particularly environmental and social outcomes, is inherently data-intensive, multidimensional, and dynamic, and thus requires frequent measurement and rapid feedback to support learning and adaptation (Burritt and Schaltegger, 2010; Neely *et al.*, 2005).

Recent advances in digital technologies offer an opportunity to fundamentally reconfigure Continuous Improvement systems. Industry 4.0 infrastructures enable real-time sensing, integration, and analysis of operational data, thereby transforming how performance is monitored and improved (Kagermann *et al.*, 2016; Igbokwe *et al.*, 2024). However, without a coherent conceptual framework, digitalization risks becoming a technology-driven initiative disconnected from improvement routines and sustainability objectives. The DCI framework addresses this gap through the explicit integration of Lean practices, digital enablement, and sustainability metrics into a unified, closed-loop improvement system.

Defining Digital Continuous Improvement (DCI)

Digital Continuous Improvement is defined as the systematic integration of Lean and Kaizen practices with digitally captured environmental, social, and economic sustainability metrics that are embedded within iterative feedback and learning cycles. DCI extends classical Kaizen by augmenting human-centered problem-solving with high-resolution, real-time data, which enhances the visibility, measurability, and scalability of sustainability improvements.

Conceptually, DCI builds on three complementary theoretical foundations: a), Lean management provides the improvement logic and routines that structure problem identification and experimentation (Liker, 2004; Shah and Ward, 2007). b), sustainability performance frameworks define the outcome space across environmental, social, and economic dimensions (Elkington, 1997; GRI, 2021). C), digitalization enables continuous measurement, rapid feedback, and data-driven learning, consistent with dynamic capability and socio-technical system perspectives (Teece, 2007; Trist and Bamforth, 1951).

Structure of the DCI Framework

Fig. 1 visually presents the four-layer architecture of Digital Continuous Improvement, showing how Lean practices (e.g., Kaizen, VSM, 5S) are digitally enabled through Industry 4.0 technologies to generate measurable environmental, social, and economic sustainability outcomes. The closed-loop feedback layer highlights continuous learning and performance refinement.

Lean Practices Layer

At the core of the framework are established Lean tools and routines, including Kaizen events, Value Stream Mapping (VSM), 5S, Total Productive Maintenance (TPM), and standard work. These practices provide the mechanisms through which improvement opportunities are identified, tested, and standardized. Importantly, DCI does not replace Lean practices; rather, it enhances their effectiveness through the expansion of the performance dimensions they address.

Digital Enablement Layer

The second layer consists of digital infrastructures that capture and integrate operational data. IoT sensors, Manufacturing Execution Systems (MES), and enterprise platforms enable continuous monitoring of energy use, material flows, equipment states, and ergonomic conditions at granular levels (Sanders *et al.*, 2016; Müller *et al.*, 2018). This layer reduces reliance on manual data collection and enables sustainability indicators to be observed in near real time.

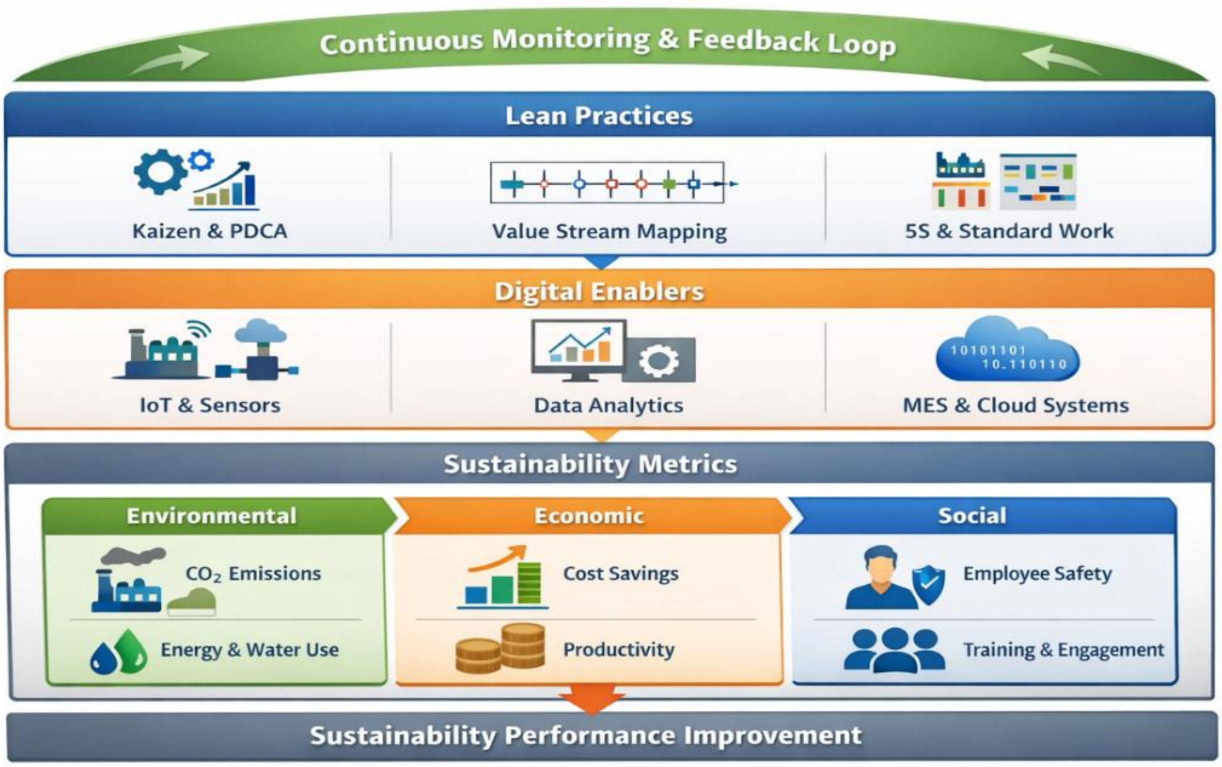

Fig. 1: Digital Continuous Improvement framework: integrating lean, digitalization, and sustainability.

Sustainability Metrics Layer

The third layer translates raw digital data into decision-relevant sustainability KPIs aligned with established standards such as ISO 14031 and the Global Reporting Initiative. Environmental indicators include energy and carbon intensity, material yield, and water consumption; social indicators capture safety, ergonomics, training, and participation; and economic indicators reflect cost, productivity, and flow efficiency. By embedding these KPIs directly into Continuous Improvement routines, DCI transforms sustainability from an abstract objective into an operational performance variable.

Feedback and Learning Layer

The outer layer closes the improvement loop through analytics-driven feedback. Visualization dashboards, statistical process control, and trend analysis enable teams to evaluate the sustainability impacts of Kaizen initiatives, compare pre and post intervention performance, and identify unintended trade-offs. This learning-oriented design aligns with continuous experimentation and organizational learning theories, which reinforce sustained performance improvement over time (Argote and Miron-Spektor, 2011).

Methodological Innovation and Measurable Sustainability Benefits

The primary methodological innovation of the DCI framework lies in its explicit coupling of improvement actions with digitally measured sustainability outcomes. Rather than inferring sustainability benefits indirectly from efficiency gains, DCI enables direct attribution of environmental and social performance changes to specific Lean interventions. Time-stamped, high-frequency data allow researchers and practitioners to treat Kaizen events as quasi-experimental interventions that support pre–post analysis, effect size estimation, and longitudinal performance tracking. This data-driven design addresses long-standing critiques of Lean–sustainability research regarding weak measurement and causal ambiguity (Martínez-Jurado and Moyano-Fuentes, 2014; Cherrafi *et al.*, 2016). By enabling process-level measurement, DCI supports more rigorous empirical testing and facilitates cross-study comparability, both of which are essential for cumulative, high-impact research.

Theoretical and Practical Relevance

From a theoretical perspective, DCI reframes Continuous Improvement as a digitally enabled dynamic capability for sustainability, thus integrating micro-level routines with macro-level performance outcomes (Teece, 2007). Practically, the framework provides organizations with a structured approach for the alignment of Lean initiatives with ESG objectives and regulatory reporting requirements, while maintaining the flexibility and employee engagement that are central to the philosophy of Kaizen. Through the articulation of clear constructs, mechanisms, and measurement pathways, the DCI framework offers a foundation for future empirical studies and cross-sectoral applications. Its integrative and data-driven nature positions it as a reference model for scholars and practitioners who are seeking for scalable solutions to contemporary sustainability challenges.

METHODOLOGY

Research Design

To examine how Lean practices can be systematically linked to measurable sustainability outcomes through digitalization, this study adopts a data-driven, multi-method research design. Consistent with recent calls for more rigorous and empirically grounded sustainability research in operations management (Seuring and Gold, 2013; Govindan, 2020), the methodology integrates conceptual development with quantitative analysis of high-resolution operational data. The design enables both theoretical generalization and methodological transparency, thereby supporting cumulative research and replication.

Specifically, the study combines –

a) a structured synthesis of extant literature to inform construct operationalization,
b) development of a Digital Continuous Improvement measurement architecture, and
c) a data-driven illustrative case that demonstrates how digitally enabled Kaizen initiatives generate measurable environmental, economic, and social sustainability benefits.

This hybrid approach aligns with established practices in operations and sustainability research where novel frameworks are supported by empirical illustration prior to large-sample testing (Ketokivi and Choi, 2014).

Empirical Context and Unit of Analysis

The empirical illustration focuses on Continuous Improvement initiatives that are implemented at the process level within an operational setting characterized by repetitive production activities and digital monitoring infrastructure. The unit of analysis is the individual process improvement intervention (i.e., Kaizen event), consistent with prior Lean research that treats improvement routines as discrete organizational actions (Shah and Ward, 2007). Each Kaizen event targets a clearly defined operational problem (e.g., energy waste, material scrap, ergonomic risk) and is supported by digital data collection before, during, and after implementation. This design enables attribution of observed sustainability performance changes to specific improvement actions rather than to aggregate organizational trends.

Data Collection and Digital Measurement Infrastructure

Data were collected through an integrated digital infrastructure comprising Internet of Things (IoT) sensors, Manufacturing Execution Systems (MES), and enterprise data platforms. These technologies enable continuous monitoring of operational variables such as energy consumption, machine utilization, cycle time, scrap rates, and selected social indicators (e.g., safety incidents, ergonomic risk proxies).

Operational data were captured at high temporal resolution (e.g., minute-level readings) and aggregated into weekly performance indicators to balance analytical robustness with managerial interpretability. Sustainability metrics were operationalized in alignment with established standards, including ISO 14031 for environmental performance evaluation and the Global Reporting Initiative for social and economic indicators. This standards-based operationalization enhances construct validity and comparability across studies (Burritt and Schaltegger, 2010).

Operationalization of Lean Practices and Sustainability Metrics

Lean practices were operationalized based on well-established definitions in the literature. Kaizen events were characterized by cross-functional team involvement, root-cause analysis, rapid experimentation, and standardization of successful solutions (Imai, 1986; Liker, 2004). Value Stream Mapping and 5S activities were used to identify sources of waste and variability, while Total Productive Maintenance supported equipment reliability improvements.

Sustainability performance was captured using a multidimensional KPI set reflecting environmental, economic, and social (ESG) outcomes (Deswal and Deswal, 2025). Environmental indicators included energy intensity (kWh per unit), material yield (%), and waste generation rates. Economic indicators included lead time, Overall Equipment Effectiveness (OEE), and cost per unit. Social indicators captured safety performance, ergonomic risk scores, and employee participation in improvement activities. By embedding these KPIs within Continuous Improvement routines, the methodology enables direct measurement of sustainability impacts at the process level.

Analytical Approach

Fig. 2 illustrates how Kaizen interventions are treated as quasi-experimental events within the DCI system. It shows the flow from real-time data capture (IoT/MES) to KPI calculation, pre- and post-performance comparison, and analytics-driven feedback. The figure clarifies how sustainability benefits are directly attributed to specific improvement actions.

The analytical strategy treats Kaizen interventions as quasi-experimental events, enabling pre–post performance comparisons using time-series data. Baseline performance was established using multiple observation periods prior to each intervention to reduce the influence of random variation. Post-intervention performance was evaluated over comparable time windows to assess the persistence of observed effects. Statistical analyses included paired mean comparison tests and effect size estimation to evaluate the magnitude of sustainability improvements. Where appropriate, control charts and trend analyses were used to distinguish sustained improvements from short-term fluctuations. This approach responds to methodological critiques of Lean–sustainability studies that rely on cross-sectional or perceptual data (Martínez-Jurado and Moyano-Fuentes, 2014).

Validity, Reliability, and Rigour

Several measures were taken to enhance research rigour. Construct validity was supported through alignment with internationally recognized sustainability standards and widely accepted Lean definitions. Internal validity was strengthened by the use of high-frequency digital data and clearly defined intervention points, reducing ambiguity in causal inference. Reliability was enhanced through automated data capture, minimizing human reporting bias.

While the illustrative nature of the empirical analysis limits statistical generalization, the methodological design emphasizes analytical generalization and replicability. By explicitly documenting data structures, KPI definitions, and analytical procedures, the study provides a transparent foundation for future large-sample and longitudinal research.

ILLUSTRATIVE CASE RESULTS

This section presents results from a data-driven illustrative case designed to demonstrate how DCI enables measurable sustainability benefits through the integration of Lean practices, digital technologies, and standardized sustainability metrics. Consistent with prior methodological exemplars in operations and sustainability research, the results emphasize effect sizes, directionality, and managerial relevance rather than statistical generalization (Ketokivi and Choi, 2014).

Overview of the Illustrative Case

The illustrative case examines a series of digitally supported Kaizen initiatives implemented at the process level over a

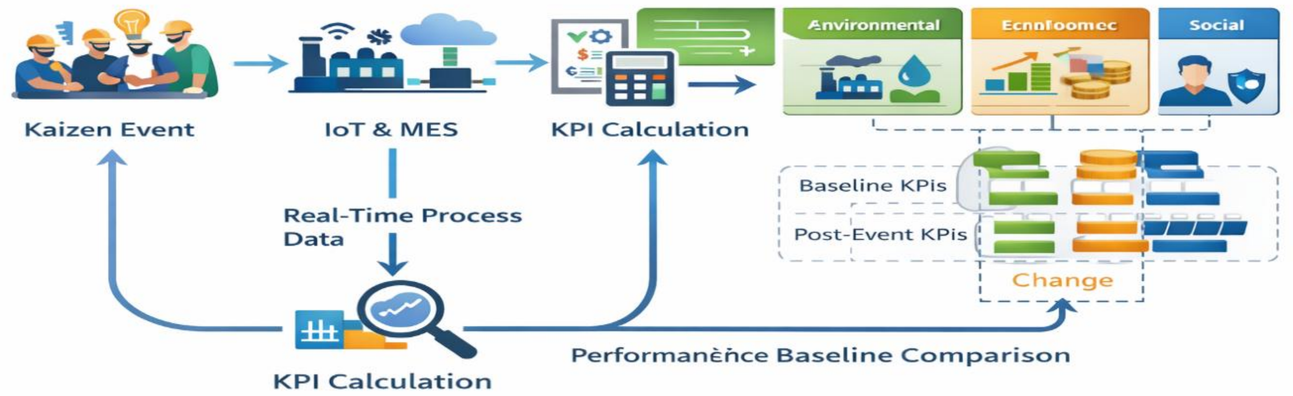

Fig. 2: Digital measurement and analytics logic linking kaizen events to sustainability outcomes.

twelve-month period. Each initiative targeted a specific source of operational waste identified through Value Stream Mapping and supported by real-time digital data. Sustainability performance was evaluated using pre- and post-intervention comparisons across environmental, economic, and social dimensions.

Baseline performance values were calculated using rolling averages from multiple observation periods prior to each intervention, while post-intervention values reflect stabilized performance following implementation. This design enables attribution of observed changes to Continuous Improvement actions rather than short-term variability.

Environmental Sustainability Performance

Table 1 summarizes changes in key environmental sustainability indicators following DCI-enabled Kaizen interventions focused on energy efficiency, material waste reduction, and process stability.

The results indicate substantial reductions in resource intensity, which is consistent with prior Lean–sustainability studies while providing stronger measurement granularity through digital data (Chiarini, 2014; Garza-Reyes *et al.*, 2018). Notably, the integration of IoT-based monitoring enabled rapid identification of abnormal energy consumption and scrap generation, thus allowing Kaizen teams to address root causes more effectively.

Economic Performance Outcomes

Economic performance improvements were observed alongside environmental gains, reinforcing the complementary relationship between sustainability and operational excellence. Table 2 reports changes in core operational performance indicators commonly used in Lean research.

These results align with established Lean performance outcomes (Shah and Ward, 2007) while demonstrating that digitally enabled sustainability improvements do not require trade-offs with economic efficiency. Instead, DCI reinforces cumulative performance gains by reducing variability and unproductive resource use.

Social Sustainability Outcomes

Social sustainability outcomes, often underrepresented in Lean–Green research, were explicitly monitored through digitally supported indicators that are related to safety, ergonomics, and employee engagement. Table 3 summarizes key results.

The observed improvements highlight how digital feedback mechanisms can enhance the human-centered foundations of Kaizen by increasing visibility of social risks and reinforcing participatory improvement behaviors (Liker and Hoseus, 2008; Longoni *et al.*, 2014).

Cross-Dimensional Performance Synthesis

Fig. 3 synthesizes environmental, economic, and social performance improvements that were achieved through Digital Continuous Improvement. Using normalized indices or percentage change bars, it visually demonstrates that sustainability gains are mutually reinforcing rather than competing, thus reinforcing the business case for integrated CI systems.

Table 1: Environmental sustainability performance before and after DCI interventions.

Indicator	Baseline (Pre-Kaizen)	Post-Kaizen	% Change
Energy intensity (kWh/unit)	12.4	9.6	−22.6%
Material yield (%)	87.5	93.2	+6.5%
Scrap rate (%)	6.8	4.9	−27.9%
Water consumption (L/unit)	18.1	14.7	−18.8%

Table 2: Economic performance outcomes associated with DCI implementation.

Indicator	Baseline	Post-Kaizen	% Change
Lead time (hours)	42.5	34.1	−19.8%
Overall Equipment Effectiveness (OEE, %)	68.2	76.9	+12.8%
Cost per unit (index)	1.00	0.86	−14.0%
Inventory turnover (times/year)	7.4	9.1	+23.0%

Table 3: Social sustainability indicators before and after DCI interventions.

Indicator	Baseline	Post-Kaizen	% Change
Recordable incident rate (per 200,000 hours)	4.3	3.2	−25.6%
Ergonomic risk score (index)	100	84	−16.0%
Kaizen participation rate (%)	48	65	+35.4%
Training hours per employee (annual)	18.6	24.9	+33.9%

Figure-level synthesis of results indicates that sustainability gains were mutually reinforcing rather than competing. Environmental improvements were closely associated with reductions in process variability and unplanned downtime, while social improvements supported more consistent standard work adherence and learning. Importantly, the availability of time-stamped digital data enabled Kaizen teams to evaluate not only whether improvements occurred, but also when and where they occurred within the process. This temporal and spatial resolution represents a significant methodological advance over traditional Lean–sustainability studies, which rely on aggregated or perceptual data.

Summary of Key Findings

Taken together, the illustrative case demonstrates that Digital Continuous Improvement enables the following: a. Direct, process-level measurement of sustainability impacts linked to specific Kaizen interventions; b. Simultaneous improvements across environmental, economic, and social performance dimensions; and c. Enhanced learning and accountability through real-time feedback and analytics. These findings

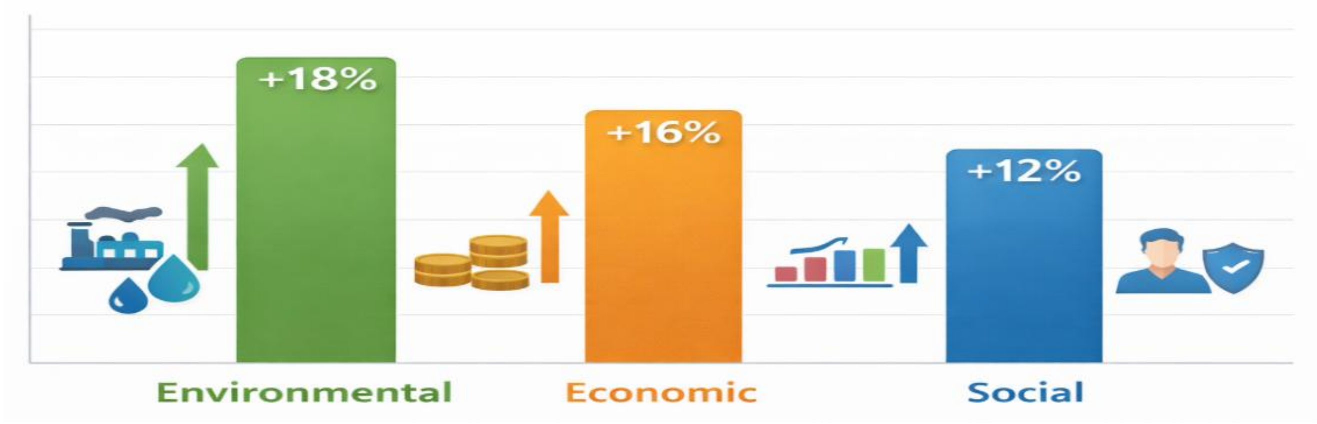

Fig. 3: Cross-dimensional sustainability performance improvements enabled by DCI.

provide empirical support for the DCI framework and illustrate its potential as a scalable, data-driven approach to integrating Lean practices with sustainability performance management.

DISCUSSION

This study set out to examine how Lean and Kaizen practices can be systematically linked to measurable sustainability outcomes through digitalization. Through proposing and empirically illustrating the DCI framework, the findings extend existing Lean–sustainability research in several important ways. The discussion below interprets the results in relation to prior literature, highlights theoretical and managerial implications, and clarifies how DCI advances both measurement rigour and practical relevance.

Interpreting the Sustainability Performance Effects of DCI

The illustrative case results demonstrate that digitally enabled Kaizen initiatives can deliver simultaneous and mutually reinforcing improvements across environmental, economic, and social sustainability dimensions. Reductions in energy intensity, material waste, and water consumption were accompanied by improvements in lead time, equipment effectiveness, and cost efficiency, supporting the argument that sustainability and operational excellence are not inherently in conflict (Porter and van der Linde, 1995; King and Lenox, 2001). Unlike much of the prior “Lean and Green” literature, which relies on aggregated or perceptual measures, the DCI approach enables direct attribution of sustainability outcomes to specific improvement actions using high-resolution operational data. This addresses a recurring critique that Lean–sustainability studies often overstate alignment without demonstrating causal mechanisms or effect sizes (Martínez-Jurado and Moyano-Fuentes, 2014; Cherrafi *et al.*, 2016). The observed magnitude of improvements is consistent with, yet more precisely measured than, those reported in earlier empirical studies (Chiarini, 2014; Garza-Reyes *et al.*, 2018).

Digitalization as a Catalyst for Sustainable Continuous Improvement

The findings highlight digitalization not merely as a supporting technology, but as a structural enabler that reshapes how Continuous Improvement is enacted and evaluated. By embedding sustainability metrics into real-time dashboards and feedback loops, DCI transforms sustainability indicators from lagging, compliance-oriented measures into operational control variables. This shift aligns with dynamic capability theory, which emphasizes the role of sensing, seizing, and reconfiguring capabilities in responding to complex environmental demands (Teece, 2007).

From a socio-technical systems perspective, DCI illustrates how digital tools and human-centered Lean routines can be jointly optimized rather than treated as substitutes (Trist and Bamforth, 1951). The increase in Kaizen participation and training observed in the illustrative case suggests that digital feedback mechanisms can strengthen, rather than undermine, employee engagement when aligned with Kaizen principles of respect for people (Liker and Hoseus, 2008).

Advancing Sustainability Measurement in Operations Research

A key contribution of this study lies in advancing sustainability measurement at the process level. By operationalizing environmental, social, and economic KPIs in alignment with ISO 14031 and GRI standards while capturing them through digital infrastructures, the DCI framework bridges the longstanding divide between sustainability reporting and operational improvement (Burritt and Schaltegger, 2010). This integration responds to calls for decision-relevant sustainability metrics that support learning rather than static disclosure (Beske-Janssen *et al.*, 2015).

Methodologically, treating Kaizen interventions as quasi-experimental events enables more rigorous assessment of sustainability impacts over time. This approach supports effect size estimation, temporal analysis, and cross-study comparability—features that are often missing in sustainability research but are essential for cumulative knowledge development (Ketokivi and Choi, 2014).

Implications for Theory Development

Theoretically, this study contributes to Lean and operations management literature by reframing Continuous Improvement as a digitally enabled sustainability capability. While prior research has conceptualized Lean primarily as an efficiency-oriented production system, the DCI framework extends its scope to explicitly encompass environmental and social value creation. In doing so, it integrates Lean thinking with sustainability and digital transformation literatures that have largely evolved in parallel. Furthermore, the framework provides a micro-to-macro linkage between shop-floor improvement routines and organizational-level sustainability outcomes. This linkage addresses a persistent gap in operations and sustainability research, where micro-level practices are often disconnected from macro-level performance indicators and policy objectives (Seuring and Gold, 2013).

Managerial and Policy Implications

For managers, the findings underscore the importance of embedding sustainability metrics directly into Continuous Improvement routines rather than managing them as separate initiatives. The DCI framework offers a practical roadmap for aligning Lean programs with ESG objectives, regulatory requirements, and stakeholder expectations, while preserving the flexibility and learning orientation central to Kaizen. From a policy perspective, DCI supports evidence-based sustainability governance by enabling verifiable, process-level performance data. This capability is increasingly relevant as regulators and investors demand greater transparency and accountability in sustainability reporting (GRI, 2021). Digital Continuous Improvement thus represents a scalable mechanism for operationalizing sustainability commitments within everyday work systems.

Summary of Key Insights

In summary, the discussion highlights three core insights. First, Lean and Kaizen practices can generate substantial sustainability benefits when supported by digital measurement and feedback systems. Second, digitalization enhances both the rigour and relevance of sustainability performance management by enabling real-time, process-level measurement. Third, the DCI framework provides a theoretically grounded and practically actionable model for integrating Continuous Improvement with sustainability objectives. Together, these insights position Digital Continuous Improvement as a promising pathway for advancing sustainable operations research and practice.

CONCLUSION AND FUTURE RESEARCH AGENDA

Conclusion

This article set out to advance understanding of how Lean and Kaizen practices can be systematically aligned with sustainability objectives in an increasingly digitalized operational environment. By introducing the Digital Continuous Improvement framework, the study reconceptualizes Continuous Improvement as a data-driven sustainability capability rather than a narrowly defined efficiency tool. Through the integration of Lean routines, digital measurement infrastructures, and multidimensional sustainability metrics, the framework demonstrates how environmental, economic, and social performance improvements can be achieved simultaneously and transparently.

The illustrative case results show that digitally enabled Kaizen initiatives can deliver measurable reductions in resource intensity, process waste, and ergonomic risk while also strengthening core operational performance. Crucially, these outcomes are not inferred indirectly but are observed at the process level through high-resolution data and structured feedback loops. This approach addresses long-standing concerns in the literature regarding weak measurement, limited causal attribution, and the separation of sustainability reporting from operational decision-making. By bridging classical Kaizen philosophy with contemporary digital technologies, the study provides both a conceptual and methodological contribution. It demonstrates that respect-for-people principles and human-centered problem-solving can be reinforced—rather than displaced—by digital tools when technology is purposefully embedded within Continuous Improvement systems. As such, Digital Continuous Improvement offers a scalable pathway for organizations seeking to translate sustainability ambitions into everyday operational practice.

Future Research Agenda

While this study establishes a foundational framework and empirical illustration, it also opens several promising avenues for future research. First, large-sample quantitative studies are needed to statistically test the relationships proposed in the DCI framework across different industries and organizational contexts. Longitudinal designs would be particularly valuable for examining the persistence of sustainability gains and the dynamic interactions between Lean routines and digital capabilities over time.

Second, future research could deepen causal analysis by employing quasi-experimental or experimental designs that compare digitally enabled Continuous Improvement systems with traditional Lean implementations. Such studies would help isolate the specific contribution of digital measurement and analytics to sustainability performance. Third, sector-specific adaptations of DCI warrant further investigation. While manufacturing contexts provide a natural starting point, service operations, healthcare systems, construction, and public-sector organizations face distinct sustainability challenges that may require tailored KPI architectures and digital tools.

Fourth, the social dimension of sustainability represents a particularly fertile area for future inquiry. More granular measurement of learning, well-being, skill development, and participatory governance could enrich understanding of how Digital Continuous Improvement shapes human and organizational outcomes. Finally, future studies could explore the broader institutional and policy implications of DCI, including its role in supporting credible sustainability reporting, regulatory compliance, and stakeholder engagement. As data-driven accountability becomes increasingly central to sustainability governance, research that connects shop-floor improvement systems with macro-level policy objectives will be especially valuable. In summary, this study positions Digital Continuous Improvement as a robust and adaptable framework for advancing sustainable operations research and practice. By combining methodological rigour with practical relevance, it invites continued scholarly engagement and empirical exploration.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

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