

Reliability-Driven Digital Transformation: Leveraging Site Reliability Engineering for Sustainable Legacy Infrastructures

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Abstract: The accelerating convergence of digital transformation and sustainability imperatives has reshaped scholarly and practical debates across engineering, management, and socio-technical systems research. Within this evolving landscape, organizations increasingly confront the challenge of maintaining reliable, scalable, and resilient digital infrastructures while simultaneously advancing environmental, social, and economic sustainability objectives. This tension is particularly pronounced in legacy infrastructures, where technical debt, organizational inertia, and resource inefficiencies intersect with rising expectations for sustainable performance. Against this backdrop, the present study develops a comprehensive, theory-driven examination of how Site Reliability Engineering (SRE) can function as a foundational enabler of sustainable digital transformation when integrated with Industry 4.0 technologies, circular economy principles, and governance frameworks for a sustainable digital world. Drawing extensively on interdisciplinary literature, this article situates SRE not merely as an operational practice but as a strategic socio-technical paradigm capable of aligning system reliability with long-term sustainability outcomes.

The study is anchored in the insight that digital sustainability cannot be achieved through technological adoption alone, but requires robust reliability mechanisms that stabilize complex systems over time. The implementation of SRE in legacy retail infrastructure, as examined by Dasari (2025), provides a critical empirical and conceptual entry point for understanding how reliability practices can mitigate systemic fragility, reduce waste, and enhance adaptive capacity in digitally transforming organizations. Building on this foundation, the article synthesizes perspectives from digital supply chain theory, Industry 4.0, sustainable entrepreneurship, and governance studies to articulate a holistic framework in which SRE operates as a connective tissue between operational excellence and sustainability performance.

Methodologically, the research adopts a qualitative, integrative design grounded in systematic literature analysis and conceptual synthesis. Rather than producing new empirical data, the study interprets and recontextualizes existing findings to generate higher-order insights into the role of reliability engineering in sustainable digital infrastructures. The results are presented as analytically derived themes that demonstrate how SRE contributes to resource efficiency, resilience, transparency, and stakeholder trust across digitally mediated systems. These findings are further elaborated through a critical discussion that engages with competing scholarly viewpoints, addresses structural and ethical limitations, and outlines future research trajectories.

By positioning SRE within the broader discourse on digital sustainability, this article makes three principal contributions. First, it extends the conceptual boundaries of SRE beyond its traditional operational domain, framing it as a sustainability-relevant practice. Second, it bridges fragmented literatures on Industry 4.0, circular economy, and digital governance through a reliability-centered lens. Third, it offers a theoretically grounded foundation for policymakers, managers, and researchers seeking to design digital infrastructures that are not only innovative and efficient but also resilient, responsible, and sustainable over time.

Keywords: Site Reliability Engineering; Digital Sustainability; Industry 4.0; Legacy Infrastructure; Sustainable Digital Transformation; Circular Economy

INTRODUCTION

The contemporary discourse on sustainability is increasingly inseparable from the realities of digital transformation, as organizations across sectors integrate advanced digital technologies into their core operational and strategic processes. This convergence has generated a growing body of scholarship examining how digitalization reshapes economic models, environmental impacts, and social relations, often under the umbrella of concepts such as Industry 4.0, digital supply chains, and sustainable entrepreneurship (Gregori & Holzmann, 2020; Khan et al., 2023). At the same time, scholars have cautioned that digital transformation is not inherently sustainable and may, under certain conditions, exacerbate energy consumption, electronic waste, and systemic inequalities if not carefully governed (Lucivero, 2020; Linkov et al., 2018). Within this tension, the question of how digital infrastructures can be designed, operated, and evolved in a manner that supports long-term sustainability objectives has emerged as a critical research challenge.

A central yet underexplored dimension of this challenge concerns system reliability. Digital infrastructures underpinning modern organizations are increasingly complex, distributed, and interdependent, making them vulnerable to failures that carry significant economic, environmental, and social costs. Reliability failures can trigger cascading disruptions across supply chains, urban systems, and service ecosystems, undermining both operational performance and sustainability commitments (Kayikci, 2018; Dwivedi & Paul, 2022). Despite this, much of the sustainability-oriented digitalization literature focuses on technology adoption, innovation diffusion, or business model transformation, while paying comparatively limited attention to the engineering and operational practices that ensure digital systems function consistently and efficiently over time.

Site Reliability Engineering (SRE) has emerged within the software and systems engineering community as a response to precisely these challenges of complexity and scale. Originating in large-scale internet organizations, SRE integrates software engineering principles with operations management to achieve highly reliable and resilient systems through automation, monitoring, and continuous improvement. While traditionally framed in terms of service availability and performance, SRE also entails practices that directly influence resource utilization, failure reduction, and system longevity, all of which bear relevance to sustainability outcomes. The implementation of SRE in legacy retail infrastructure, as analyzed by Dasari (2025), illustrates how reliability-focused transformation can address entrenched inefficiencies while enabling modernization without wholesale system replacement, thereby reducing waste and environmental impact.

Legacy infrastructures represent a particularly salient context for examining the sustainability implications of SRE. Many organizations operate on aging technological foundations that were not designed for contemporary digital demands or sustainability expectations. Replacing these systems outright is often economically and environmentally prohibitive, leading organizations to pursue incremental modernization strategies that must contend with technical debt and operational fragility. Research on Industry 4.0 and maintenance 4.0 highlights the sustainability potential of digitally enhanced maintenance and reliability practices, emphasizing predictive capabilities and resource optimization (Jasiulewicz-Kaczmarek et al., 2020). However, these discussions rarely engage explicitly with SRE as a structured approach to managing reliability at scale.

The literature on digital sustainability further underscores the need for integrative frameworks that align technological innovation with environmental and social value creation. Gregori and Holzmann (2020) argue that digital technologies can enable sustainable entrepreneurship when embedded within business models that prioritize long-term value over short-term efficiency gains. Similarly, Epifani (2020) emphasizes that digital transformation must be understood as a socio-technical process in which organizational culture, governance, and ethical considerations shape sustainability outcomes. These perspectives suggest that operational practices such as SRE should be analyzed not only for their technical efficacy but also for their broader systemic implications.

In parallel, supply chain and logistics scholars have explored how digitalization influences sustainability through enhanced transparency, coordination, and circularity. Dwivedi and Paul (2022) propose a digital supply chain framework aligned with circular economy principles, highlighting the role of data integration and process reliability in minimizing waste and environmental impact. Blockchain-based approaches to

circular resource management further illustrate how reliable digital infrastructures are prerequisite for trust and accountability in sustainability-oriented systems (Gong et al., 2022). Yet, the underlying reliability engineering practices that support such infrastructures remain largely implicit in these analyses.

The governance dimension adds another layer of complexity to the discussion. Linkov et al. (2018) contend that a sustainable digital world requires governance strategies capable of managing systemic risks and uncertainties inherent in digital technologies. Reliability failures represent a key source of such risk, with implications for public trust and institutional legitimacy. In urban contexts, for example, the application of artificial intelligence to sustainable cities depends on robust and reliable digital systems to deliver promised benefits without unintended harm (Gupta & Degbelo, 2023). These insights reinforce the argument that reliability is not a purely technical concern but a governance-relevant attribute of digital sustainability.

Despite these converging strands of literature, a clear gap persists in the integration of SRE into sustainability-focused digital transformation research. While Dasari (2025) provides an important case-based exploration of SRE in legacy retail environments, the broader theoretical implications of SRE for sustainable digital infrastructures remain underdeveloped. Specifically, there is a need to articulate how SRE practices intersect with Industry 4.0 technologies, circular economy logics, and sustainability governance frameworks to produce systemic benefits beyond traditional performance metrics.

This article addresses this gap by developing a comprehensive, theoretically grounded analysis of SRE as a catalyst for sustainable digital transformation. Rather than treating SRE as a narrowly defined engineering methodology, the study conceptualizes it as a socio-technical paradigm that aligns reliability, efficiency, and adaptability with sustainability objectives. Through an extensive synthesis of interdisciplinary literature, the research examines how SRE contributes to environmental sustainability by reducing waste and energy inefficiencies, to economic sustainability by enhancing system resilience and cost-effectiveness, and to social sustainability by supporting reliable service delivery and stakeholder trust.

The remainder of the article is structured to progressively build this argument. The methodology section outlines the qualitative, integrative approach adopted to synthesize diverse scholarly perspectives and justify the interpretive lens employed. The results section presents analytically derived themes illustrating the sustainability-relevant outcomes of SRE integration. The discussion section engages in deep theoretical interpretation, situating these findings within ongoing scholarly debates, addressing limitations, and identifying avenues for future research. The conclusion synthesizes the core insights and reflects on their implications for research and practice in sustainable digital transformation.

METHODOLOGY

The methodological approach adopted in this study is an integrative, qualitative, and theory-driven framework designed to examine the intersection of Site Reliability Engineering (SRE) and sustainable digital transformation in legacy infrastructures. Unlike empirical studies relying on primary data collection, the focus here is on constructing a rigorous, conceptual analysis grounded in extant interdisciplinary literature. The rationale for this approach is multifold. First, the study addresses a conceptual gap regarding the sustainability implications of SRE, which has been largely discussed in operational or software engineering contexts but not extensively theorized in relation to broader socio-technical and environmental considerations (Dasari, 2025). Second, digital sustainability is an inherently multi-dimensional construct encompassing environmental, economic, and social dimensions, necessitating a methodology capable of synthesizing heterogeneous literatures, from Industry 4.0 and digital supply chains to circular economy frameworks and governance studies (Dwivedi & Paul, 2022; Gregori & Holzmann, 2020).

The study proceeds through several structured steps to ensure methodological rigor and analytical depth. The first phase involves a systematic literature identification and review. Relevant peer-reviewed journal articles, conference proceedings, and authoritative reports were selected based on their thematic alignment with three key pillars: SRE and reliability engineering, digital transformation/Industry 4.0 practices, and sustainability outcomes. Special attention was given to studies offering empirical, theoretical, or conceptual insights into the

operationalization of reliability practices in complex digital systems (Jasiulewicz-Kaczmarek et al., 2020; Khan et al., 2023). The prioritization of Dasari (2025) ensured that the discussion of legacy retail infrastructure remained central, providing an applied context in which theoretical constructs could be anchored.

Once the literature corpus was identified, the second phase entailed an integrative coding and thematic analysis. Each selected study was examined for contributions related to reliability practices, digital process integration, resource efficiency, and sustainability outcomes. Coding was iterative and reflexive, emphasizing the identification of emergent patterns and conceptual linkages. For instance, concepts such as predictive maintenance, automated monitoring, and failure mitigation were coded not only as operational features but also in terms of their environmental and social impact implications (Jasiulewicz-Kaczmarek et al., 2020; Mocerino, 2018). The integration of circular economy literature further enabled the exploration of SRE practices' role in minimizing waste and promoting systemic resource optimization (Gong et al., 2022).

The third phase of the methodology involves analytical synthesis, which entails the translation of coded themes into higher-order conceptual frameworks. This process is grounded in interpretive reasoning, seeking to articulate causal and relational linkages between reliability engineering practices and sustainability outcomes. For instance, the implementation of automated monitoring in legacy systems can be theoretically linked to reductions in resource wastage and energy inefficiency, which in turn contribute to environmental sustainability (Hassoun et al., 2022). Similarly, SRE-driven practices enhancing system resilience can be linked to economic sustainability by mitigating the costs associated with system downtime and operational disruption (Dasari, 2025). This synthesis relies on a cross-pollination of insights from multiple disciplines, reflecting the socio-technical complexity of sustainable digital transformation.

An important component of the methodology is critical discussion and triangulation. The study intentionally juxtaposes contrasting perspectives to highlight potential trade-offs and tensions inherent in SRE implementation. For example, while SRE emphasizes automation and predictive analytics, these practices may involve substantial computational and energy overheads, raising questions about net environmental benefit (Lucivero, 2020). By critically engaging with such debates, the methodology allows for a nuanced understanding of sustainability implications and avoids oversimplified or normative assertions. Furthermore, the study examines potential limitations associated with transferring SRE practices across organizational contexts. Legacy infrastructures vary widely in their technological configurations, human resource competencies, and cultural readiness for digital transformation, all of which influence the applicability and impact of SRE (Millard et al., 2018).

The methodological design also addresses epistemological considerations. The integrative literature-based approach aligns with interpretivist and constructivist traditions, acknowledging that sustainability outcomes are context-dependent and socially mediated. By grounding analysis in a combination of empirical findings and conceptual frameworks, the study situates SRE within broader debates about socio-technical resilience, governance, and value creation in the digital era (Linkov et al., 2018; Flórez-Parra et al., 2024). This approach also permits the inclusion of both direct and indirect pathways through which SRE practices influence sustainability, such as through enabling trust in digital systems, facilitating transparency, or supporting policy compliance.

To ensure validity and reliability within this qualitative framework, the study adheres to several procedural safeguards. First, the literature corpus was selected to include peer-reviewed sources with established credibility, reducing the risk of bias from unverified claims. Second, the coding and thematic analysis followed iterative and reflexive procedures, including cross-validation against multiple sources to mitigate selective interpretation. Third, the study explicitly situates findings in the context of established theoretical frameworks, such as Industry 4.0, circular economy, and sustainable entrepreneurship, providing conceptual grounding that enhances interpretive rigor (Gregori & Holzmann, 2020; Dwivedi & Paul, 2022).

Limitations of this methodology are acknowledged. The reliance on secondary literature precludes direct empirical validation of findings in specific organizational contexts. Additionally, while the integrative approach allows for broad conceptual synthesis, it is inherently interpretive and may not capture all possible

contextual nuances of SRE implementation across diverse industries. Nonetheless, the approach is appropriate for the study's primary objective: to generate a theoretically robust understanding of how reliability-centered practices can contribute to sustainable digital transformation in legacy infrastructures. The methodology provides a structured and defensible platform from which subsequent results and discussion can meaningfully engage with interdisciplinary scholarly insights.

RESULTS

The analytical synthesis yielded a set of interrelated findings that elucidate the potential of SRE practices to enhance sustainability across environmental, economic, and social dimensions. The results are organized around three overarching themes: resource efficiency and environmental impact reduction, resilience and economic sustainability, and governance and social value creation.

Resource Efficiency and Environmental Impact Reduction

One of the primary mechanisms through which SRE contributes to sustainability is the optimization of resource use and reduction of environmental impact. Automated monitoring, predictive failure analysis, and incident mitigation protocols reduce the frequency and severity of system downtime, which in turn diminishes unnecessary computational cycles, energy consumption, and associated greenhouse gas emissions (Lucivero, 2020; Mocerino, 2018). In the context of legacy retail infrastructures, Dasari (2025) documents how SRE practices led to a measurable reduction in redundant system operations, lowering energy overhead while simultaneously improving service responsiveness.

Furthermore, integration of SRE with digital supply chain management facilitates circularity by ensuring that systems supporting inventory management, logistics, and waste tracking operate reliably and accurately. Dwivedi and Paul (2022) emphasize that digital reliability is critical for circular economy initiatives, as data inconsistencies or system failures can result in material losses and inefficiencies. Similarly, blockchain-enabled tracking mechanisms, which depend on highly reliable system operations, can prevent leakage of materials in circular processes (Gong et al., 2022). SRE thus functions as an enabler of environmentally responsible digital ecosystems, ensuring that digital processes themselves do not generate avoidable waste.

Resilience and Economic Sustainability

SRE practices are closely linked to economic sustainability through the enhancement of organizational resilience. By mitigating system failures, enabling rapid recovery, and supporting predictive maintenance, SRE reduces the financial and operational costs associated with downtime, lost productivity, and corrective interventions (Jasiulewicz-Kaczmarek et al., 2020; Dasari, 2025). In legacy infrastructures, where technical debt and outdated hardware/software configurations exacerbate vulnerability, the deployment of SRE practices represents a cost-effective alternative to wholesale system replacement.

Moreover, SRE facilitates the continuous evolution of digital infrastructures, enabling organizations to integrate Industry 4.0 technologies, such as IoT-enabled sensors and predictive analytics platforms, without destabilizing existing operations (Khan et al., 2023; Mian et al., 2020). This incremental modernization reduces capital expenditure while maintaining operational continuity, illustrating a pathway through which reliability-centered digital practices contribute to long-term economic viability.

Governance and Social Value Creation

The third theme emerging from the analysis concerns governance and social sustainability. Reliable digital infrastructures underpin trust in systems that deliver essential services, ranging from retail operations to urban resource management. Linkov et al. (2018) highlight that governance frameworks for a sustainable digital world rely on the assurance that technological systems operate predictably and transparently. SRE practices, by embedding monitoring, automated alerting, and post-incident analysis, enhance accountability and support stakeholder confidence.

Additionally, reliable systems facilitate social sustainability outcomes by ensuring service continuity and equitable access. For example, in retail and supply chain contexts, system failures disproportionately affect vulnerable populations by limiting access to essential goods or causing operational disruptions (Flórez-Parra et al., 2024). By proactively managing reliability, SRE mitigates such disparities and supports the fulfillment of broader social sustainability goals. Furthermore, SRE integration can catalyze organizational culture change, promoting proactive problem-solving, collaborative learning, and continuous improvement—behaviors that align with principles of sustainable digital transformation (Gregori & Holzmann, 2020).

Cross-Cutting Observations

Several cross-cutting insights emerge from the synthesis of these themes. First, SRE functions not merely as a set of technical practices but as a systemic enabler of sustainable digitalization, linking operational efficiency with strategic sustainability objectives. Second, the sustainability impact of SRE is context-dependent, with the greatest benefits observed in organizations operating legacy infrastructures where unreliability carries disproportionate environmental, economic, and social costs (Dasari, 2025). Third, the integration of SRE with complementary frameworks—Industry 4.0 technologies, circular economy principles, and governance mechanisms—amplifies its potential to generate holistic sustainability outcomes (Dwivedi & Paul, 2022; Gong et al., 2022).

These results collectively underscore the value of positioning reliability engineering as a central concern in digital sustainability discourse. By stabilizing complex systems, minimizing waste, and fostering resilience, SRE practices provide a concrete operational pathway through which organizations can achieve environmentally responsible, economically viable, and socially equitable outcomes.

DISCUSSION

The discussion extends the interpretive analysis of the results, situating SRE within theoretical and practical debates on digital sustainability, exploring its broader implications, and addressing limitations and future research directions.

SRE as a Sustainability-Oriented Paradigm

Traditionally, SRE has been conceived as an operational methodology aimed at achieving high system availability and performance. However, this research positions SRE as a sustainability-oriented paradigm, arguing that reliability engineering inherently produces environmental, economic, and social benefits. This perspective resonates with the concept of digital sustainable entrepreneurship, wherein the embedding of technology within organizational processes generates broader societal value beyond profit maximization (Gregori & Holzmann, 2020). By formalizing reliability as a central operational principle, SRE aligns the technical architecture of digital infrastructures with strategic sustainability objectives, enabling organizations to simultaneously pursue performance and responsibility goals.

Sustainability scholars have long emphasized the importance of systemic approaches that integrate technical, organizational, and societal dimensions (Hassoun et al., 2022; Millard et al., 2018). From this standpoint, SRE provides a concrete mechanism through which abstract sustainability principles are operationalized. Predictive monitoring, incident response automation, and post-mortem analyses, while designed to enhance system uptime, also reduce energy consumption, minimize redundant resource utilization, and enhance stakeholder trust. This dual effect highlights the unique capacity of reliability engineering to bridge operational excellence with sustainability imperatives, a linkage that is often underappreciated in existing literature.

Integration with Industry 4.0 and Circular Economy Principles

A critical insight emerging from the study is the synergistic potential of integrating SRE with Industry 4.0 technologies and circular economy frameworks. Industry 4.0 emphasizes real-time data collection, predictive analytics, and interconnected systems, which inherently increase the complexity and potential fragility of digital infrastructures (Khan et al., 2023; Mian et al., 2020). SRE practices provide the operational scaffolding

necessary to manage this complexity, ensuring that advanced technologies enhance sustainability rather than inadvertently introducing new inefficiencies or vulnerabilities.

Circular economy literature further contextualizes the role of SRE in sustainability by highlighting the importance of accurate, reliable information flows for material recovery, reuse, and recycling (Dwivedi & Paul, 2022; Gong et al., 2022). System failures or data inconsistencies in digital supply chains can undermine circular processes, leading to waste or misallocation of resources. By embedding reliability practices, organizations can ensure that digital infrastructures support circularity objectives, thereby linking operational stability with environmental responsibility.

Governance and Ethical Implications

The discussion of SRE's contribution to sustainability extends beyond technical and operational dimensions to encompass governance and ethical considerations. Digital systems operate within broader socio-technical ecosystems where reliability failures can have cascading societal impacts (Linkov et al., 2018; Flórez-Parra et al., 2024). By enhancing predictability and transparency, SRE supports the ethical stewardship of digital infrastructures, reinforcing trust and accountability.

Moreover, the proactive orientation of SRE practices aligns with principles of responsible innovation. The monitoring, incident analysis, and iterative improvement mechanisms central to SRE provide structured avenues for identifying unintended consequences and addressing systemic risks. This is particularly relevant in legacy infrastructures, where historical design limitations and technical debt increase vulnerability to failures with ethical and societal ramifications (Dasari, 2025).

Limitations and Future Research Directions

Despite its conceptual contributions, the study has several limitations. First, the reliance on secondary literature precludes empirical verification of findings in specific organizational contexts, limiting the ability to quantify the sustainability impacts of SRE. Second, the transferability of SRE practices across industries and geographies requires further investigation, particularly in sectors with distinct regulatory, cultural, or technological constraints (Millard et al., 2018). Third, while SRE's environmental, economic, and social benefits are theoretically substantiated, trade-offs and unintended consequences—such as energy overhead from automated monitoring or ethical concerns associated with algorithmic decision-making—require more empirical scrutiny (Lucivero, 2020).

Future research should address these limitations through longitudinal, mixed-methods studies that evaluate the operationalization of SRE within sustainability-oriented digital transformations. Comparative studies across industries and regions can elucidate contextual contingencies, while quantitative analyses can measure the magnitude of environmental, economic, and social impacts. Additionally, research can explore the integration of SRE with emerging governance frameworks, blockchain-enabled circularity solutions, and AI-driven predictive maintenance systems to generate evidence-based guidelines for policy and practice.

Theoretical Implications

From a theoretical standpoint, the study advances the conceptualization of reliability engineering as an enabler of sustainable digital transformation. By positioning SRE at the nexus of operational, environmental, and social considerations, the research expands the traditional boundaries of both SRE and digital sustainability literatures. It also highlights the importance of multi-level analysis, demonstrating that operational practices at the system level can have far-reaching sustainability implications at organizational and societal scales.

Practical Implications

For practitioners, the study underscores the strategic value of embedding SRE into legacy infrastructures as a pathway to sustainability. By focusing on reliability, organizations can achieve multiple objectives simultaneously: reducing environmental impact, enhancing economic resilience, and fostering stakeholder

trust. The findings suggest that investment in SRE should not be perceived solely as a cost or technical upgrade but as a strategic lever for responsible and sustainable digital transformation.

CONCLUSION

This study presents a comprehensive, theoretically grounded exploration of Site Reliability Engineering as a catalyst for sustainable digital transformation. By synthesizing insights from SRE literature, Industry 4.0 frameworks, circular economy principles, and governance studies, the research demonstrates that reliability-centered practices provide significant environmental, economic, and social sustainability benefits. In legacy infrastructures, where technical debt and operational fragility present barriers to modernization, SRE offers a practical and strategic mechanism for achieving sustainability objectives while maintaining system performance.

The findings extend the conceptual boundaries of SRE, positioning it as a sustainability-oriented socio-technical paradigm rather than a narrowly defined operational methodology. By stabilizing complex systems, reducing resource waste, enhancing resilience, and promoting trust, SRE integrates technical excellence with strategic sustainability goals. These insights have implications for scholars, practitioners, and policymakers seeking to design, govern, and manage digital infrastructures that are innovative, efficient, and socially responsible.

Future research should empirically validate these conceptual claims, explore cross-industry applicability, and investigate integration with emerging digital governance and circularity initiatives. Ultimately, the study contributes to a holistic understanding of how reliability engineering can underpin sustainable digital infrastructures, ensuring that technological advancement aligns with long-term environmental, economic, and social objectives.

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