Digitally Enabled Sustainability Transitions:

The Role of Technological Innovation and Institutional Readiness in Advancing Environmental Performance

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Abstract: Rapid digital transformation is reshaping pathways toward sustainable development and environmental governance. Emerging technologies such as artificial intelligence, blockchain, and the Internet of Things are increasingly deployed to enhance environmental monitoring, optimize resource use, and strengthen accountability across industries. Yet, their contribution to sustainability transitions remains uneven, particularly in developing and emerging economies where institutional readiness varies significantly. This conceptual paper makes an original contribution by integrating digital innovation, institutional theory, and dynamic capabilities theory into a unified framework that explains how digital technologies translate into environmental performance under different institutional conditions. Drawing on an extensive review of interdisciplinary literature, the study develops a novel conceptual model linking technological adoption, institutional readiness, and organizational capabilities to sustainability outcomes. The paper identifies critical barriers, including regulatory fragmentation, digital divides, financial constraints, and limited technical capacity, that constrain green digital transformation. By theorizing the joint and conditional effects of digital innovation and institutional readiness, the study advances sustainability transitions scholarship and provides actionable insights for policymakers and organizations seeking to leverage digitalization for environmental performance, particularly in institutionally diverse contexts.

INTRODUCTION

Over the past decade, a growing body of scholarship has highlighted the expanding role of digital transformation in environmental management and sustainability transitions. Emerging technologies, most notably artificial intelligence (AI) (Gursoy & Cai, 2025), the Internet of Things (IoT) (Mishra & Mishra, 2025), blockchain (Islam, 2023), cloud computing (Al-Sharafi et al., 2023), and big data analytics (Pauwels & Aksehirli, 2025), are increasingly recognized as critical tools for enhancing environmental monitoring, strengthening traceability, and optimizing resource use. Rashid & Kausik (2024) observe that these technologies have transformed the generation of real-time environmental intelligence, while Cheng et al. (2024) argue that such digital capabilities support predictive modelling of environmental hazards and foster transparency across global supply chains. As global pressure to meet climate and sustainability commitments intensifies, digital technologies have become essential enablers of new environmental governance models and sustainability pathways (Y. Wang et al., 2025).

Despite their promise, the adoption and impact of digital technologies remain uneven and highly context-dependent. Studies show that although advanced economies have made substantial progress in integrating digital tools into sustainability efforts, many developing and emerging economies continue to face structural obstacles that limit effective technological uptake. Li (2025) describes these disparities as "digital sustainability divides," pointing to gaps in digital infrastructure, regulatory coordination, and human capital development. Even where digital tools are introduced, institutional constraints often undermine their effectiveness. Handoyo (2024) reports that weak governance systems, unclear regulatory frameworks, and limited technical expertise hinder the translation of digital investments into improved environmental outcomes. Similarly, Cardillo & Basso (2025) note that fragmented and conflicting institutional arrangements create inconsistent implementation environments, thereby weakening the effectiveness of digital sustainability initiatives.

Despite rapid advances in digital technologies, their contribution to sustainability transitions remains highly uneven across regions and sectors. In many developing and emerging economies, digital investments fail to translate into improved environmental performance due to institutional fragmentation, weak regulatory enforcement, and limited organizational capabilities. This misalignment between technological potential and institutional readiness constitutes a central challenge for digitally enabled sustainability transitions.

The sustainability transitions literature provides useful conceptual tools for understanding these challenges. The multi-level perspective (MLP) outlined by Figueira et al. (2025) suggests that transitions arise through interactions among landscape pressures, socio-technical regimes, and niche innovations. Several scholars argue that digital technologies increasingly function as niche innovations with the potential to disrupt established unsustainable regimes (Massa et al., 2023; van der Loos et al., 2024). Yet the extent to which these technologies catalyze sustainability transitions varies substantially across institutional contexts. Tomassi & Kinyondo (2024), for instance, show that in settings characterized by regulatory uncertainty or weak enforcement, digital sustainability initiatives often lose momentum despite their technical viability.

Institutional theory offers further insight into this variability. Lounsbury et al. (2011) conceptualize institutional environments as comprising regulative, normative, and cognitive pillars that shape organizational behaviour and technological adoption. Dimaggio & Powell (1983) emphasize that organizations respond to these institutional pressures through isomorphic processes, aligning with prevailing regulations, norms, and cultural expectations. Recent studies applying institutional theory to digitalization show that strong environmental regulations accelerate digital adoption (Ţigănaşu et al., 2025), while normative pressures related to ESG reporting encourage investment in digital monitoring tools (Erokhin, 2025). Conversely, where institutional pillars are weak, fragmented, or contradictory, digital technologies tend to be adopted superficially, generating limited environmental impact.

Dynamic capabilities theory complements these perspectives by explaining why organizations vary in their ability to derive environmental benefits from digital innovation. According to Chaudhuri et al. (2024), organizations must possess the capability to sense emerging opportunities, seize them through appropriate investment and reconfiguration, and transform internal routines to embed new technologies effectively. Recent studies demonstrate that firms with higher digital maturity and stronger transformative capabilities are better positioned to deploy AI-enabled monitoring systems, IoT sensors, and blockchain-based traceability tools to improve the environment (Bindeeba et al., 2025; Westergren et al., 2024). In contrast, organizations lacking these capabilities struggle to convert digital investments into measurable sustainability outcomes.

Despite these advances, the literature exhibits several essential gaps. First, most studies assess digital technologies in isolation rather than as interconnected systems that jointly influence environmental performance (Guandalini, 2022). Second, limited research integrates technological, institutional, and organizational perspectives to explain why digital sustainability outcomes differ across contexts (Nichifor et al., 2025). Third, although empirical studies on digital sustainability are proliferating, conceptual work that offers integrated frameworks, particularly those connecting digital innovation, institutional readiness, and sustainability transitions, remains scarce (Sahibzada et al., 2025). As a result, there is no integrated theoretical explanation of how digital innovation, institutional readiness, and organizational capabilities jointly shape environmental performance within sustainability transitions.

This conceptual paper directly addresses these gaps by developing an integrative framework that combines digital innovation, institutional theory, and dynamic capabilities theory to explain environmental performance within sustainability transitions. The framework elucidates how digital technologies influence sustainability outcomes, the institutional conditions under which they are most effective, and the organizational capabilities required to translate digital adoption into measurable environmental improvements.

To guide this effort, the paper addresses three central research questions: (1) How do digital technologies contribute to sustainability transitions and environmental performance? (2) What forms of institutional readiness are necessary to support the effective adoption and implementation of digital sustainability innovations? (3) How do technological capabilities, organizational routines, and institutional conditions interact to shape the pathways and pace of digitally enabled sustainability transitions?

By addressing these questions, the paper makes three contributions. First, it synthesizes and integrates fragmented strands of scholarship on digital transformation, sustainability transitions, and institutional theory. Second, it proposes a new conceptual framework that explains the joint influence of technological innovation and institutional readiness on environmental outcomes. Third, it offers actionable insights for policymakers, development partners, and organizations seeking to leverage digital transformation for sustainable development, particularly in contexts where institutional capacities remain uneven.

The remainder of the paper is organized as follows: it begins with a review of the literature on digital transformation, sustainability transitions, and digital innovation in developing economies. This is followed by a discussion of the theoretical foundations underpinning the study. A subsequent section identifies key gaps in existing research. The paper then introduces the proposed conceptual framework and accompanying propositions, followed by a discussion of the framework's implications. Another section examines the barriers and challenges associated with digital sustainability transitions. The paper concludes by outlining future research directions and offering closing reflections.

METHODOLOGY

Research design

This study adopts a qualitative conceptual research design aimed at theory development rather than empirical testing. Conceptual research is appropriate where the objective is to integrate fragmented bodies of knowledge, develop explanatory frameworks, and advance theoretical understanding of complex phenomena (Jaakkola, 2020). Given the interdisciplinary and emerging nature of digitally enabled sustainability transitions, a conceptual approach allows for systematic synthesis across digital innovation, sustainability transitions, and institutional scholarship.

Literature identification and selection

The conceptual framework was developed through an extensive and structured review of peer-reviewed literature spanning digital transformation, sustainability transitions, environmental performance, dynamic capabilities, and institutional theory. Relevant studies were identified using major academic databases (e.g., Scopus, Web of Science, and Google Scholar) with keywords including digital innovation, sustainability transitions, institutional readiness, environmental performance, AI, IoT, and blockchain. Priority was given to high-quality journal articles, recent empirical studies, and foundational theoretical works.

Analytical approach

The reviewed literature was analyzed thematically to identify recurring constructs, mechanisms, and relationships. Particular attention was paid to how digital technologies influence environmental outcomes, how institutional contexts shape adoption and effectiveness, and how organizational capabilities mediate these processes. Insights from Dynamic Capabilities Theory and Institutional Theory were then systematically integrated to construct the proposed conceptual framework and derive theoretically grounded propositions.

Ethical considerations

This study is based exclusively on secondary data from published academic sources and does not involve human participants or primary data collection. Ethical standards relating to academic integrity, proper citation, and responsible interpretation of prior research were strictly observed throughout the research process

LITERATURE BACKGROUND

Digital transformation in environmental management

Digital transformation refers to the integration of advanced digital technologies, such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, and big data analytics, into organizational and societal processes to enhance decision-making and operational efficiency (Verhoef et al., 2021). AI enables predictive modelling and pattern recognition in large environmental datasets. At the same time, IoT networks provide continuous, high-frequency sensory information from environmental assets such as water systems, energy grids, and agricultural landscapes (Shobanke et al., 2025). Blockchain, on the other hand, offers immutable audit trails that strengthen transparency and traceability, particularly in carbon markets and supply chain environmental reporting (Kumar et al., 2025). Big data analytics synthesizes vast, heterogeneous datasets to generate actionable insights on emissions trends, resource flows, and ecological risks.

A growing body of literature shows that digital technologies are increasingly central to environmental monitoring and resource optimization. For example, IoT sensors have been used to optimize water consumption in smart agriculture and reduce methane emissions through real-time livestock monitoring (Rajak et al., 2023). AI-powered models enhance energy efficiency by predicting demand patterns and automating load balancing in renewable energy grids (Shobanke et al., 2025). Blockchain systems have been applied to improve the credibility of carbon offsets and enhance the accuracy of environmental, social, and governance (ESG) reporting. Studies also indicate that digital tools support regulatory compliance by automating environmental audits and improving the quality of sustainability disclosures (Suta & Tóth, 2023).

Scholars such as Goel et al. (2024) and H. Cheng et al. (2024)observe that digitalization significantly improves environmental performance by enabling firms to transition from reactive environmental management to proactive, data-driven strategies. However, the literature also cautions that digital transformation outcomes vary widely across regions and industries. The effectiveness of these technologies depends not only on their technical capabilities but also on the institutional environments in which they are deployed, a theme explored in later sections of this review.

Understanding sustainability transitions

Sustainability transitions refer to long-term, systemic changes that shift socio-technical systems, such as energy, agriculture, manufacturing, and transportation, toward more sustainable modes of production and consumption (Biely & Chakori, 2025). Transition Theory conceptualizes these changes as multi-dimensional processes shaped by interactions between technological innovation, institutional evolution, and societal preferences (Möller et al., 2025). The Multi-Level Perspective (MLP) is widely used to explain these transitions and situates them across three analytical levels: the landscape, the regime, and niches.

At the landscape level, broad factors such as climate change pressure, global sustainability agendas, and technological megatrends create external forces that destabilize existing systems. The regime level comprises the dominant socio-technical structures, rules, norms, infrastructures, and business practices that shape stability and resistance to change. Niche-level innovations, often small-scale or experimental, serve as protected spaces where new technologies or practices can develop before scaling.

Digital technologies increasingly function as catalysts within this framework. Scholars observe that AI and IoT-based systems help destabilize unsustainable regimes by revealing inefficiencies, externalities, and hidden environmental costs (Pimenow et al., 2025). Digital innovations also strengthen niche development by enabling low-cost experimentation, supporting decentralized energy systems, and opening new pathways for citizen engagement through open data platforms (Mavlutova et al., 2025). Furthermore, digitalization accelerates the diffusion of green practices by lowering transaction costs, enhancing transparency, and facilitating coordination among multiple actors.

Thus, within the transition's literature, digital technologies are viewed not merely as tools but as strategic enablers of systemic environmental change. Their potential to transform value chains, governance models, and regulatory processes positions them as core drivers of sustainability transitions.

Digital innovation in developing economies

Digital innovation in developing economies presents a complex landscape characterized by both transformative potential and significant structural constraints (Chen & Xing, 2025). On one hand, emerging technologies offer opportunities to leapfrog traditional infrastructures, improve resource management, and enhance environmental governance. For instance, mobile-based data collection platforms have enabled low-cost environmental monitoring in agriculture (Almalki et al., 2021), while decentralized renewable energy systems allow rural communities to bypass grid limitations. Developing economies also stand to benefit from digital traceability tools that improve compliance with international environmental standards, thereby enhancing market competitiveness.

However, the challenges remain substantial. A persistent digital divide, manifested in unequal access to broadband connectivity, limited digital literacy, and affordability barriers, constrains the adoption of advanced technologies. Infrastructure deficits, such as unreliable electricity and weak data ecosystems, further limit the scalability of digital solutions. Additionally, organizational and institutional capacity gaps, including inadequate technical expertise, fragmented regulatory frameworks, and weak enforcement mechanisms, impede the effective integration of digital tools into environmental management systems.

Scholars such as Gkrimpizi et al. (2023) argue that these constraints often result in isolated pilot projects, ‘islands of digital excellence’, that show technological promise but fail to scale due to weak institutional alignment and inadequate long-term support. Other studies highlight that digital innovation in developing contexts tends to be donor-driven, raising concerns about long-term sustainability and local ownership (Alojail & Khan, 2023). Moreover, without coordinated policy support, firms in these economies face uncertainty regarding technology standards, data governance norms, and investment incentives.

While digital innovation holds significant promise for environmental management in developing economies, its transformative impact remains highly dependent on institutional readiness, governance coherence, and the availability of enabling infrastructure. Understanding these contextual dynamics is crucial for designing effective digital sustainability strategies.

Theoretical foundations

The theoretical underpinnings of this study draw on Dynamic Capabilities Theory (DCT) and Institutional Theory (IT). These frameworks provide complementary lenses for understanding how digital innovation interacts with organizational capacity and institutional environments to drive sustainability transitions.

Dynamic capabilities theory

Dynamic Capabilities Theory, as articulated by Teece et al. (1997), emphasizes an organization’s ability to sense, seize, and transform in response to changing environments. In the context of digital sustainability, these capabilities explain why some organizations can leverage emerging technologies to improve environmental performance, while others struggle.

i. Sensing digital opportunities: Organizations must continuously scan both internal and external environments to identify technological opportunities and emerging environmental challenges. Studies by Olawade et al. (2024) and Miller et al. (2025) show that firms employing AI and IoT for predictive environmental monitoring are more effective when they actively sense trends in regulatory requirements, technological innovations, and stakeholder expectations.

ii. Seizing technologies: Once opportunities are identified, organizations must mobilize resources, invest in technology, and implement appropriate digital solutions. This phase involves decision-making, resource allocation, and the creation of partnerships with technology providers or research institutions. For instance, blockchain adoption for carbon traceability depends on coordinated investments in infrastructure, workforce upskilling, and process redesign (Soe et al., 2025).

iii. Transforming Organizational Routines: Finally, dynamic capabilities require firms to reconfigure internal processes and embed digital technologies into routine operations. Transforming organizational routines ensures that environmental performance improvements are sustainable over time. Studies suggest that companies with adaptive routines, such as integrating IoT-based energy monitoring into production schedules, achieve more consistent sustainability outcomes than those with rigid structures (Khan et al., 2025).

Dynamic capabilities thus provide a robust framework for understanding how organizations translate digital adoption into tangible environmental performance gains, emphasizing the importance of organizational agility, strategic foresight, and continuous learning.

Institutional theory

While dynamic capabilities focus on organizational processes, Institutional Theory explains how external pressures and norms shape technological adoption. According to Scott (2008) and DiMaggio & Powell (1983), institutions influence organizations through three interrelated pillars: regulative, normative, and cognitive.

i. Regulative pillar (laws and policies): Regulatory frameworks, including environmental legislation, emission standards, and ESG reporting requirements, provide formal rules that compel or incentivize the adoption of digital solutions. For example, Ramadan et al. (2024)found that firms in countries with strict environmental regulations were more likely to implement IoT-enabled monitoring systems to comply with reporting obligations.

ii. Normative pillar (industry standards and social expectations): Beyond formal regulations, organizations respond to expectations from professional associations, industry consortia, and societal norms. Firms may adopt AI or blockchain tools to meet emerging standards or stakeholder expectations regarding environmental transparency. Mukherjee et al. (2025) emphasize that normative pressures can be particularly influential in shaping adoption when regulatory enforcement is weak but social and market expectations are high.

iii. Cognitive pillar (cultural beliefs and digital literacy): The cognitive pillar reflects shared understandings, cultural beliefs, and the level of technological literacy within a society or organization. High digital literacy facilitates technology adoption and reduces resistance to change, while entrenched cultural beliefs about technology or environmental responsibility can either accelerate or constrain adoption (Shonubi, 2025).

Institutional theory highlights that digital adoption does not occur in isolation; instead, it is embedded within complex socio-political, regulatory, and cultural systems. The theory explains why similar technological solutions may produce divergent outcomes across regions or industries, depending on the strength and coherence of institutional pillars.

Integrating the two theories

Integrating Dynamic Capabilities Theory and Institutional Theory provides a comprehensive framework for understanding digital sustainability transitions:

i. Dynamic capabilities explain how organizations internally sense, seize, and transform to adopt digital technologies.

ii. Institutional theory explains how external forces shape the adoption, scaling, and effectiveness of these technologies.

Together, these theories suggest that successful digital sustainability initiatives require both organizational agility and institutional support. A firm may possess the capability to implement AI-driven monitoring systems, but without supportive regulations, industry norms, and cultural acceptance, the technology may fail to deliver environmental impact. Conversely, strong institutions may promote digital adoption, but without dynamic capabilities, organizations may struggle to integrate technologies effectively into operations.

LITERATURE REVIEW

Digital tools for environmental transparency

Digital technologies have emerged as pivotal tools for enhancing environmental transparency in organizations. Several studies emphasize that blockchain, IoT, and AI are particularly influential in enabling accurate, verifiable, and timely environmental data collection and reporting.

Blockchain for traceability: Blockchain technology provides a decentralized, immutable ledger that enhances transparency and traceability in environmental and supply chain management. According to Bhatt & Emdad (2025), blockchain applications in carbon markets and sustainable supply chains have enhanced the credibility of emissions reporting and enabled sustainability claims to be verified by multiple stakeholders. Similarly, Al Amin et al. (2025) observed that blockchain-based systems allow organizations to track resource use across complex supply chains, reducing opportunities for greenwashing and enabling accountability in environmental reporting.

IoT for real-time environmental monitoring: The Internet of Things (IoT) enables continuous monitoring of environmental parameters, including energy consumption, water usage, air quality, and waste generation. El-Afifi et al. (2024) highlight that IoT sensors provide high-frequency, real-time data, enabling organizations to detect inefficiencies, optimize resource use, and respond quickly to environmental risks. For instance, smart water management systems in agriculture employ IoT-enabled irrigation to reduce water waste while maintaining crop productivity, demonstrating tangible environmental benefits.

AI for predictive environmental analytics: Artificial intelligence (AI) complements IoT and blockchain by analyzing large volumes of environmental data to predict trends and risks. Several scholars, including Olawumi & Oladapo (2025), demonstrate that AI-driven predictive analytics can forecast emissions patterns, anticipate energy demand fluctuations, and optimize resource allocation in industrial processes. AI systems thus enable proactive rather than reactive environmental management, contributing to more strategic sustainability decision-making.

Collectively, these technologies support enhanced transparency, traceability, and accountability, which are critical for sustainability transitions. However, literature also notes that adoption is uneven, often influenced by organizational readiness, regulatory frameworks, and sector-specific requirements.

Environmental performance in organizations

Environmental performance encompasses an organization's ability to minimize negative ecological impacts while efficiently utilizing natural resources. Scholars define environmental performance through multiple indicators, including energy efficiency, carbon emissions, waste reduction, and compliance with sustainability reporting standards such as ESG (Environmental, Social, and Governance) and GRI (Global Reporting Initiative) (Dobre et al., 2025; Khatri & Kjærland, 2023).

Research shows that digitalization plays a significant role in improving environmental performance by increasing accuracy, accountability, and operational efficiency. Atofarati et al. (2025) observed that IoT-enabled monitoring systems allow organizations to detect environmental inefficiencies in real time, while AI models help forecast resource requirements and reduce overconsumption. Blockchain, in turn, strengthens credibility in sustainability reporting, ensuring that ESG disclosures are reliable and verifiable. Scholars argue that digital tools facilitate the transition from compliance-oriented environmental management to strategic, proactive sustainability practices (Abbes, 2025). Despite these advances, the literature emphasizes that the benefits of digitalization for environmental performance are highly context-dependent. Factors such as institutional readiness, regulatory support, organizational capabilities, and technological infrastructure significantly influence the effectiveness of digital tools.

Gaps identified

While existing literature has demonstrated the potential of digital technologies for environmental transparency and performance, several gaps remain:

i. Fragmented adoption: Most studies examine individual technologies, AI, IoT, or blockchain, in isolation, without exploring how integrated digital systems collectively enhance sustainability outcomes. This fragmented perspective limits understanding of synergies among multiple digital tools.

ii. Limited integration of institutional context: Few studies explicitly consider how institutional factors, such as regulatory frameworks, industry norms, and socio-cultural beliefs, affect digital adoption and environmental performance. Overlooking these contextual factors can result in misaligned digital sustainability strategies that fail to achieve intended outcomes.

iii. Lack of integrated frameworks: There is a shortage of conceptual frameworks that integrate digital innovation, organizational capabilities, and governance structures to explain environmental performance comprehensively. While dynamic capabilities and institutional theories have been applied separately, their integration in a conceptual model linking digital technologies to sustainability transitions is underdeveloped.

Addressing these gaps is essential to advancing both theory and practice. A conceptual framework that integrates digital innovation, institutional readiness, and dynamic capabilities can provide a coherent lens for understanding and guiding sustainability transitions, particularly in contexts where institutional and technological capacities vary.

Conceptual framework and propositions

This section presents the core contribution of the conceptual paper: a framework that integrates digital innovation, institutional readiness, dynamic capabilities, and environmental performance. Drawing on insights from the literature and the theoretical foundations outlined in previous sections, the framework illustrates the mechanisms through which digital technologies can enable sustainability transitions in organizations.

Proposed framework

The proposed framework (Figure 1) positions digital innovation as the primary driver of environmental performance, with its effectiveness moderated by institutional readiness and mediated by dynamic capabilities. The model conceptualizes environmental performance as a multidimensional construct encompassing transparency, resource efficiency, and accountability.

i. Digital innovation: Refers to the adoption and integration of emerging digital technologies, such as AI, IoT, blockchain, and big data analytics, for environmental monitoring, reporting, and optimization.

ii. Institutional readiness: Represents the external regulatory, normative, and cognitive supports that facilitate or constrain digital adoption.

iii. Dynamic capabilities: Capture the organizational ability to sense opportunities, seize technologies, and transform routines to embed digital solutions effectively.

iv. Environmental performance: Encompasses measurable improvements in sustainability outcomes, including resource efficiency, transparency in reporting, and accountability to stakeholders.

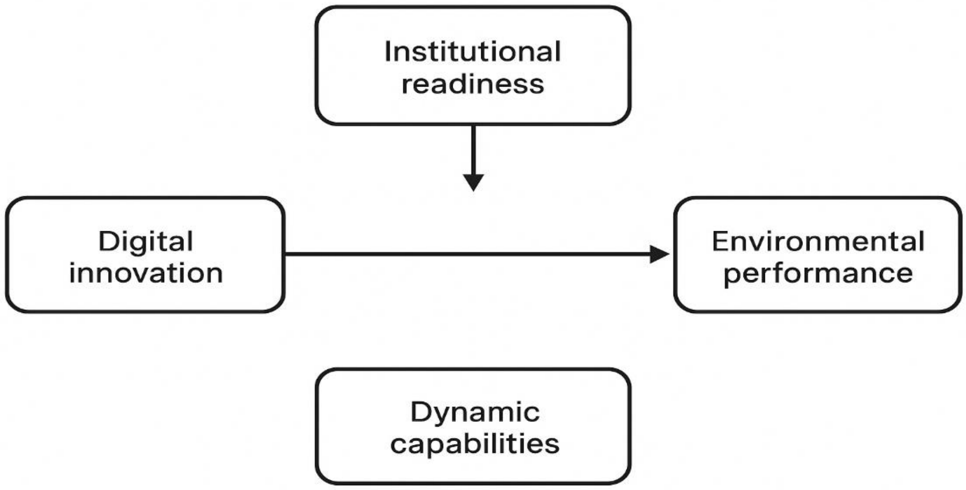

Figure 1: Conceptual framework linking digital innovation, institutional readiness, dynamic capabilities, and environmental performance

Key constructs

The framework integrates several key constructs derived from literature:

i. Digital capacity: The technical skills, expertise, and knowledge within an organization required to deploy and utilize digital tools effectively.

ii. Technological infrastructure: Physical and digital infrastructure supporting the deployment of AI, IoT, blockchain, and data analytics.

iii. Regulatory support: The presence of clear environmental policies, standards, and enforcement mechanisms that encourage or mandate digital adoption.

iv. Organizational readiness: The internal preparedness of an organization, including leadership commitment, culture, and processes, to integrate digital technologies.

v. Transparency: The ability to provide verifiable, accurate, and accessible environmental data for internal and external stakeholders.

vi. Resource efficiency: Improved utilization of natural and organizational resources, such as energy, water, and raw materials, through digital monitoring and optimization.

vii. Accountability: The extent to which organizations can demonstrate compliance with environmental regulations, reporting standards (e.g., ESG, GRI), and stakeholder expectations.

Propositions

The framework leads to several propositions that articulate the expected relationships between constructs:

P1: Digital innovation positively influences environmental performance.

Digital technologies improve monitoring, reporting, and optimization, thereby enhancing transparency, resource efficiency, and accountability.

P2: Institutional readiness strengthens the relationship between digital innovation and environmental performance.

Regulatory clarity, normative pressures, and cognitive support facilitate the effective adoption of digital tools, amplifying their impact on sustainability outcomes.

P3: Dynamic capabilities mediate the effectiveness of digital tools in sustainability transitions.

Organizations that can sense, seize, and transform opportunities enabled by digital technologies are more likely to achieve meaningful improvements in environmental performance.

P4: Weak institutional environments limit the impact of digital innovation on sustainability outcomes.

In contexts characterized by weak regulation, poor enforcement, or low cultural acceptance, digital technologies are unlikely to translate into meaningful environmental outcomes.

P5: Integrated digital systems (AI, IoT, blockchain) produce greater environmental performance gains than isolated technologies.

Synergistic deployment of multiple digital tools enables comprehensive monitoring, predictive analytics, and traceable reporting, thereby enhancing the overall sustainability impact.

Theoretical linkages

The framework synthesizes Dynamic Capabilities Theory and Institutional Theory:

i. Dynamic capabilities explain how organizations internally manage and leverage digital technologies to transform routines and enhance performance.

ii. Institutional theory clarifies the role of external pressures—regulative, normative, and cognitive, in shaping adoption, scaling, and impact.

This integrated approach highlights that digitalization alone is insufficient; organizational capacity and institutional support are necessary to convert technological potential into measurable environmental outcomes.

DISCUSSION

The proposed conceptual framework provides an integrative perspective on how digital innovation, institutional readiness, and dynamic capabilities jointly influence environmental performance. This discussion critically situates the framework within existing scholarship and highlights its theoretical, practical, and policy contributions.

Advancing theory

The framework contributes to theory in three primary ways. First, it integrates Digital Innovation, Dynamic Capabilities, and Institutional Theory, bridging a gap in the literature where these perspectives have been mainly examined in isolation. Prior studies have explored AI, IoT, and blockchain applications for environmental monitoring (Nichifor et al., 2025; Nuryanto et al., 2024), yet few have connected technological adoption with organizational capabilities and institutional context. By synthesizing these strands, the framework provides a holistic understanding of how digital technologies enable sustainability transitions.

Second, the framework emphasizes the mediating role of dynamic capabilities. While studies by Teece et al. (1997) have highlighted organizational capabilities in technology adoption, this model extends the theory to environmental performance outcomes, demonstrating that digital tools are practical only when organizations possess the capacity to sense, seize, and transform opportunities. This addresses a critical gap regarding fragmented technology adoption in sustainability research.

Third, the framework incorporates institutional readiness as a moderating factor, thereby advancing the application of institutional theory to digital sustainability. Previous work (Sadaoui et al., 2025) has shown that regulatory clarity, normative pressures, and cognitive readiness influence technology adoption, but integration with organizational capability models remains limited. The framework explicitly shows how institutional support strengthens or constrains the impact of digital innovation on environmental performance, offering a more nuanced theoretical explanation for divergent outcomes across contexts.

Insights for firms adopting digital sustainability tools

For organizational practitioners, the framework underscores the importance of building digital capacity and dynamic capabilities. Firms that actively invest in technological infrastructure, train personnel, and develop adaptive processes are better positioned to translate digital tools into tangible sustainability outcomes (Jamil et al., 2025).

Moreover, the framework highlights that technology adoption should be integrated rather than piecemeal. Combined systems, linking IoT monitoring with AI analytics and blockchain-based traceability, can achieve greater efficiency, transparency, and accountability than isolated implementations (Kashem et al., 2025). Firms are encouraged to view digital sustainability as a strategic capability, requiring cross-functional coordination and continuous learning rather than a one-time technological upgrade.

Implications for policymakers in developing economies

The framework also provides essential guidance for policymakers, especially in developing economies where institutional and technological capacities may be limited. Regulatory and normative supports, such as clear environmental legislation, ESG reporting guidelines, and industry standards, can facilitate the adoption of digital sustainability technologies (Khamisu & Paluri, 2024).

Capacity-building initiatives, including digital literacy programs, technical training, and investment in ICT infrastructure, are crucial for enabling both firms and public institutions to implement and scale digital solutions effectively. Policymakers can further incentivize adoption through subsidies, tax incentives, or partnerships with technology providers, addressing barriers such as cost constraints and infrastructure gaps (R. Wang et al., 2024).

By strengthening institutional readiness, governments can ensure that technological potential translates into meaningful environmental outcomes, mitigating the risk of failed or underutilized digital interventions.

Digital technologies as accelerators of sustainability transitions

The framework reinforces the notion that digital technologies act as catalysts for sustainability transitions, consistent with Transition Theory and the Multi-Level Perspective (Schmidt-Scheele & Mattes, 2025). Digital tools enhance niche-level innovations by enabling experimentation, improving transparency, and lowering transaction costs, thereby facilitating regime shifts toward more sustainable socio-technical systems (Zhang & Bilawal Khaskheli, 2025).

Empirical studies support this perspective. AI-enabled predictive analytics and IoT-based monitoring systems allow organizations to preemptively address environmental inefficiencies, while blockchain ensures accountability and reduces information asymmetry (Agya et al., 2025). These mechanisms accelerate transitions by improving decision-making quality, fostering stakeholder trust, and enabling system-wide coordination across organizations and sectors.

Importance of institutional readiness and capacity building

Finally, the discussion highlights the critical role of institutional readiness in enabling digital sustainability. Even the most advanced digital tools are unlikely to deliver meaningful environmental performance improvements without supportive regulatory frameworks, social norms, and cultural acceptance (Scott, 2008; Mensah et al., 2023).

Capacity-building initiatives at organizational and societal levels are therefore essential. Firms must develop dynamic capabilities to sense, seize, and transform digital opportunities, while governments and industry bodies must provide the regulatory and infrastructural support needed. The alignment between internal capabilities and external institutional conditions is fundamental to achieving sustained and scalable sustainability transitions.

BARRIERS AND CHALLENGES

Despite the significant potential of digital technologies to accelerate sustainability transitions, several barriers can impede their adoption, effectiveness, and scalability. These challenges are particularly salient in developing economies, where institutional, infrastructural, and socio-economic constraints intersect with technological innovation.

Digital Divide and Infrastructure Limitations

The digital divide, characterized by unequal access to internet connectivity, computing resources, and digital literacy, remains a critical barrier to sustainability transitions. In regions with low broadband penetration or unreliable electricity supply, the deployment of IoT sensors, AI analytics, and blockchain systems is severely constrained (Nižetić et al., 2020).

Infrastructure limitations hinder the integration of digital tools across organizational and societal levels, preventing real-time monitoring, accurate data collection, and predictive analytics. Consequently, organizations may adopt piecemeal solutions that fail to produce system-wide sustainability improvements, slowing the pace of transitions and exacerbating inequalities between digitally advanced and underserved regions.

Regulatory Fragmentation and Weak Enforcement

Fragmented or inconsistent regulatory frameworks significantly limit the effectiveness of digital sustainability initiatives. Weak enforcement of environmental laws, the absence of clear standards for ESG reporting, and conflicting policies across sectors reduce firms' incentives to invest in advanced digital technologies (Ahenkan et al., 2025).

Regulatory uncertainty discourages innovation and adoption, as organizations face risks of non-compliance, unclear data reporting requirements, and a lack of recognition for sustainability performance improvements. This barrier can stall the scaling of digital tools, even when technical capacity exists, thereby impeding sustainability transitions at the regime level.

Capacity, skills, and cultural barriers

Organizational and societal capacities, particularly technical skills, managerial expertise, and digital literacy, play a central role in determining the success of digital sustainability initiatives. Firms often struggle to integrate AI, IoT, and blockchain solutions effectively due to limited expertise or resistance to change in organizational routines (Choi et al., 2020).

Cultural beliefs and low awareness of digital sustainability practices can further constrain adoption. For example, in contexts where technology is viewed primarily as a cost rather than a strategic enabler, managers may resist integrating digital tools into environmental management processes. These barriers undermine the sensing, seizing, and transforming capabilities essential for leveraging digital innovation in sustainability transitions.

Cost and adoption risks

The financial implications of deploying digital sustainability solutions present another significant challenge. High initial investment costs for IoT infrastructure, AI systems, and blockchain platforms can be prohibitive, particularly for small and medium-sized enterprises (SMEs) in developing economies (Boonmee et al., 2025).

Additionally, perceived adoption risks, including uncertainty about return on investment, technological obsolescence, and integration challenges, may deter firms from committing resources. Without appropriate incentives, subsidies, or support mechanisms, the cost barrier can limit the scale and pace of digital sustainability transitions, restricting them to early adopters or donor-funded pilot projects.

Cybersecurity and data governance challenges

The deployment of digital technologies for environmental management generates vast amounts of sensitive data, including operational, supply chain, and environmental metrics. Weak cybersecurity and inadequate data governance frameworks pose risks of data breaches, manipulation, and loss of trust among stakeholders (Maraveas et al., 2024).

These challenges affect both organizational adoption and stakeholder confidence, potentially undermining transparency and accountability goals. In turn, cybersecurity and data governance risks can slow the diffusion of digital tools, reduce their effectiveness in monitoring and reporting, and impede sustainability transitions across sectors.

FUTURE RESEARCH DIRECTIONS

The proposed conceptual framework provides a comprehensive lens for understanding how digital innovation, institutional readiness, and dynamic capabilities jointly influence environmental performance. However, as a conceptual study, it presents opportunities for further empirical validation, refinement, and contextual exploration. The following areas represent promising directions for future research:

Empirical validation of the conceptual model

While the framework synthesizes theory and literature, empirical studies are needed to test its applicability in real-world organizational settings. Future research could adopt case study, survey, or mixed-method approaches to examine how digital technologies are adopted in diverse organizational contexts and how institutional factors shape their effectiveness in driving sustainability transitions.

Quantitative testing of propositions

The propositions outlined in the paper provide specific, testable relationships among digital innovation, institutional readiness, dynamic capabilities, and environmental performance. Quantitative research, employing structural equation modeling (SEM) or regression-based approaches, could assess the strength, direction, and significance of these relationships. Such studies would allow scholars to empirically validate the mediating role of dynamic capabilities and the moderating role of institutional readiness, providing robust evidence for theory development.

Cross-country comparisons

Given the contextual variability in institutional environments, digital infrastructure, and regulatory systems, cross-country studies are essential to understand how digital sustainability transitions differ globally. Comparative research could identify best practices, highlight contextual enablers or constraints, and examine the scalability of digital sustainability solutions across developed and developing economies.

Sector-specific studies

Different sectors present unique sustainability challenges and opportunities for digital adoption. Future research could focus on energy, agriculture, manufacturing, or supply chain sectors to examine sector-specific adoption patterns, environmental impacts, and organizational capabilities. For example, IoT and AI adoption in precision agriculture may have distinct dynamics compared to blockchain-based traceability in manufacturing supply chains. Sector-specific studies would provide actionable insights tailored to the operational realities of each domain.

Digital governance and policy studies

Institutional readiness emerged as a critical determinant of successful digital adoption. Future studies could examine digital governance frameworks, regulatory incentives, and policy interventions that enable or constrain sustainability transitions. Research could explore how government policies, industry standards, and public-private partnerships foster adoption, ensure accountability, and mitigate risks related to cybersecurity, data governance, and technological obsolescence.

CONCLUSION

This paper set out to explore how digital innovation, institutional readiness, and dynamic capabilities jointly influence environmental performance, offering a conceptual framework for understanding digitally enabled sustainability transitions. The purpose was to integrate fragmented strands of literature on emerging digital technologies, organizational capabilities, and institutional environments, providing a holistic lens for analyzing sustainability outcomes across diverse contexts.

The main conceptual contribution of the study lies in its integrative framework, which connects digital innovation, institutional readiness, and dynamic capabilities to explain environmental performance. By linking these constructs, the paper extends theory in several ways. For example, it highlights the mediating role of dynamic capabilities in transforming digital opportunities into tangible environmental gains. It emphasizes the moderating influence of institutional support on the effectiveness of digital tools. This framework addresses existing gaps in the literature, particularly the lack of models that simultaneously account for technological, organizational, and institutional dimensions of sustainability transitions.

The findings underscore that digital innovation alone is insufficient to achieve meaningful sustainability outcomes. Effective deployment of AI, IoT, blockchain, and other emerging technologies requires alignment with institutional structures, regulatory frameworks, and socio-cultural expectations. Institutional readiness, including supportive policies, normative pressures, and cognitive acceptance, ensures that digital investments translate into improved transparency, resource efficiency, and accountability. Similarly, dynamic organizational capabilities are essential for sensing opportunities, seizing technological solutions, and transforming internal routines to embed sustainability into operational practices.

From a practical and policy perspective, the framework offers guidance for firms, governments, and development agencies. Organizations are encouraged to invest in technological capacity, foster adaptive routines, and integrate digital tools strategically to maximize environmental performance. Policymakers, particularly in developing economies, should focus on strengthening regulatory frameworks, promoting digital literacy, and providing incentives to facilitate the adoption of sustainable digital technologies.

Ultimately, this conceptual study highlights the synergistic potential of digital innovation and institutional readiness in advancing sustainable development. By bridging technological potential with organizational and institutional capacities, the framework provides a roadmap for accelerating digitally enabled sustainability transitions, contributing to theory, guiding practice, and informing policy in an era of rapid digital transformation and environmental urgency.

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