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Leading sustainable digital transformation

The role of digital leadership in digital and green economy

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Abstract

Introduction/Main Objectives: Sustainable digital transformation is increasingly becoming a strategic agenda for public and private organizations to increase competitiveness while achieving sustainability targets. This study aims to explore the role of digital leadership in guiding transformation that is innovative, responsible, and aligned with sustainability principles.

Background Problems: The increasing global demand for a digital economy and a green economy requires organizations to integrate technology while considering social and environmental impacts. However, many organizations still focus on technology adoption without developing the adaptive and collaborative culture necessary for sustainable transformation. Furthermore, the suboptimal innovation ecosystem involving government, industry, and society is a barrier to maximizing the benefits of digital transformation for sustainable development.

Research Methods: This study uses a conceptual analysis approach to examine how digital leaders guide sustainable transformation through strategic vision, talent management, technology utilization, and the integration of sustainability principles into the organization's business model.

Finding/Results: The study shows that effective digital leadership emphasizes not only the adoption of technologies such as artificial intelligence, data analytics, and automation, but also building an organizational culture that is adaptive, collaborative, and sensitive to environmental impacts. Digital leaders play a crucial role in creating a cross-stakeholder innovation ecosystem that connects digital economy goals—efficiency, scalability, and technology-based added value—with green economy goals such as emissions reduction, energy efficiency, and a circular economy.

Conclusion: This study emphasizes that digital transformation strategies must be designed comprehensively, considering environmental, social, and governance (ESG) dimensions. Digital leadership serves as a catalyst capable of navigating the complexities of technology and sustainability, and plays a role in guiding organizations toward a green, inclusive, and sustainable digital economy. This study provides both conceptual contributions and practical implications for organizations transitioning to sustainability-based business models.

Keywords: Leading sustainable; digital transformation; digital leadership; digital economy; green economy.

Introduction

In the era of globalization and accelerated technological innovation, organizationswhether private companies, government agencies, or non-profit institutions—are faced with the demand to undertake digital transformation (DT) to remain relevant, competitive, and responsive to changes in the external environment. Developments in information technology, artificial intelligence, big data, automation, and digital platforms have shifted traditional operational and business paradigms toward more efficient, flexible, and data-driven ones. Many organizations are adopting digital technologies in their internal processes, services, and interactions with stakeholders. However, digital transformation should not be viewed solely as technology adoption. To achieve long-term results and comprehensive positive impacts, DT must be implemented with a sustainable approach, taking into account environmental, social, and governance aspects, and aligning with green economy principles.

The need for sustainable digital transformation is increasingly pressing as the world faces the challenges of climate change, environmental degradation, and global economic uncertainty. This is where the concept of "sustainable digital transformation" emerges as a new paradigm that combines digitalization with sustainability. Numerous literature shows that the long-term success of DT is determined not only by technology but also by the quality of leadership. In particular, the role of digital leadership is crucial. As revealed in a recent study, leaders who are able to combine a digital vision with sustainability values can drive organizations to become more innovative, resilient, and responsible towards the environment and communities (Hariyani, Hariyani, & Mishra, 2020).

Traditional leadership styles, which often focus on hierarchy, top-down control, and a sole profit-oriented approach, are deemed inadequate to address the complexities of the digital era and the demands of sustainability. In response, the concepts of adaptive leadership and digital leadership have emerged, emphasizing not only technological fluency but also the ability to create a flexible, collaborative, and future-oriented organizational culture (Ariedera, A. 2025). Digital leaders are seen as agents of change who can facilitate the integration of digital technology while promoting environmentally and socially sound business practices (Qiao, Li, & Hong, 2024). Furthermore, digital transformation coupled with green digital innovation can directly strengthen an organization's capability to compete sustainably. With the right digital leadership, organizations can implement digital solutions—such as process automation, energy efficiency, improved resource management, and cross-ecosystem collaboration—that support green economy goals while enhancing competitiveness. (Hussein et al., 2024).

However, empirically and conceptually, several challenges and gaps remain in the literature and practice. Several studies show that even if organizations have implemented digital transformation, long-term success is not guaranteed if leadership is not supportive or aligned with the sustainability mission (Pujisari et al., 2025). Furthermore, there are structural barriers such as legacy systems, a lack of adequate human resource skills, fragmented governance, and the difficulty of aligning economic and environmental goals (Hariyani, Hariyani, & Mishra, 2020).

Against this background, this article seeks to fill the conceptual and practical gaps by exploring the central role of digital leadership in facilitating sustainable digital transformation, namely a transformation that not only drives efficiency and innovation but also supports a green economy and environmental-social responsibility. In doing so, this article seeks to unify two often-separated domains: the digital economy and the green economy. Therefore, the questions to be answered in this article are: (1) What are the characteristics and strategies of effective digital leadership in supporting sustainable digital transformation? (2) How can digital leadership drive integration between digital transformation and environmental

sustainability/green economy goals? (3) What are the main challenges in implementing sustainable digital transformation, and how can leaders overcome them?

The main objective of this article is to develop a conceptual framework that explains the role and mechanisms of digital leadership in facilitating sustainable digital transformation, while also offering practical recommendations for organizations seeking to transition to a digital and green economy simultaneously. By establishing this framework, it is hoped that this article will contribute to both academic literature and modern management practice, particularly for organizations in developing countries facing pressure to advance digitally while simultaneously pursuing sustainability missions.

Research Methods

This article uses a conceptual-analytical approach, which aims to develop a conceptual framework for designing an impactful higher education model through the integration of technology and humanization-oriented collaboration. This approach was chosen because the issues studied are multidimensional and require a synthesis of theories across fields, including higher education, digital technology, organizational collaboration, and human-centered learning. According to Snyder (2019), a conceptual approach allows the author to "integrate existing knowledge and generate new perspectives through critical analysis and cross-disciplinary synthesis." In the context of higher education research, this approach is relevant because it allows for the formulation of theoretical ideas that can serve as a basis for subsequent empirical research. This article does not collect primary data from the field, but rather constructs a conceptual model based on mapping the latest scientific literature, educational policies, and documented good practices at various universities over the past five years.

The literature used includes reputable scientific journals, academic books, industry reports, and policy publications related to digital transformation, sustainability, and digital leadership. The selection was conducted purposively, considering relevance, source credibility, recency of publications (especially within the last five years), and the literature's contribution to strengthening the main argument. The primary focus was on literature discussing the integration of technology, leadership, and sustainability principles in an organizational context.

The analysis was conducted through content analysis of key concepts found in the literature, which were then synthesized to establish logical relationships between the variables and phenomena studied. The synthesis was conducted by grouping the findings based on key themes such as strategic vision of digital leadership, organizational culture, technology adoption, innovation ecosystem, and ESG integration. This process resulted in a conceptual framework that illustrates the role of digital leaders in achieving sustainable digital transformation.

The validity of the argumentation is maintained through the use of credible literature sources, theoretical triangulation, and consistency in reasoning between the concepts of digital leadership, digital transformation, and sustainability. Reliability is strengthened by ensuring that the arguments constructed can be traced back to relevant scientific references and replicated through similar literature reviews. The use of a systematic conceptual framework also helps maintain the coherence and logical rigor of the entire article.

Result and Discussion

1. Digital Leadership as the Main Driver of Sustainable Digital Transformation

Digital leadership plays a primary role in driving the success of sustainable digital transformation because it unites three critical domains: technological understanding, strategic agility, and sustainability orientation. Digital transformation itself has evolved rapidly in response to technological change, but since the emergence of global agendas such as the Paris Agreement, the UN Sustainable Development Goals, and the European Green Deal, digital transformation has begun to be associated with efforts to reduce carbon emissions, increase resource efficiency, and create greener economic value. Visionary digital leaders are able to integrate these two major agendas—digitalization and sustainability—to form a strategy that is not only adaptive but also ecologically and socially responsible.

A literature review indicates that digital leadership is a leader's ability to articulate a digital vision, facilitate innovation, and strategically navigate technological change (Borowska, 2019; Gfrerer, Rademacher, & Dobler, 2021). In the context of sustainability, these characteristics are expanded through the leader's ability to link digital decisions to environmental, social, and governance (ESG) criteria. This aligns with the findings of El Hilali et al. (2022) argue that digital leaders must not only understand the potential of technology but also be able to communicate the strategic significance of its use for long-term sustainability. In practice, sustainability-oriented digital leadership functions as a sense-giving agent. It helps organizations understand the urgency of adopting digital technologies to support energy efficiency, process decarbonization, and supply chain transparency.

This digital leadership capacity becomes increasingly important in an uncertain business environment, where technology use often raises strategic and ethical ambiguities (Bennis, 2013; Westerman et al., 2014). Therefore, digital leadership is a strategic enabler that not only facilitates technology adoption but also ensures that technology is used for purposes consistent with sustainability. A clear digital vision, the ability to design sustainable strategies, and sensitivity to the environmental implications of technology choices are the most important foundations for initiating a sustainable digital transformation.

2. Organizational Capabilities as Mediators between Leadership and Sustainability

Organizational capabilities are a crucial link between digital leadership vision and sustainability implementation. Classic literature on dynamic capabilities (Teece, 2007; Teece, Pisano & Shuen, 1997) emphasizes that an organization's ability to sense change (sensing), seize opportunities (seizing), and reconfigure resources (reconfiguring) determines a company's ability to adapt to the digital era. In the context of sustainability, sensing involves identifying green innovation opportunities, while reconfiguring involves shifting business processes toward lower emissions. One important dimension of organizational capability is an adaptive digital culture. This culture encourages employees to be open to change, collaborative, and experimental. A study by Bharadwaj et al. (2013) showed that companies with a digital business culture tend to innovate and utilize technology more quickly. When this culture is combined with sustainability values, organizations not only adopt new technologies but also do so in an environmentally friendly manner. Rai et al. (2019) added that a mature digital culture encourages the use of data in decision-making, which can be applied to monitor environmental impacts and optimize resource consumption.

Human capital capability also plays a crucial role. Employees with high digital literacy are able to understand the potential of green technologies and use them effectively. The OECD (2020) report emphasized that the lack of digital skills is a major barrier to the digital transition, particularly in developing countries. In the context of sustainability, these digital skills are

closely linked to the ability to use environmental analytics tools, IoT sensors for energy management, or enterprise resource planning (ERP) systems with sustainability modules. Furthermore, digital governance is a key capability. This governance encompasses how data is managed, how technology is selected, and how digital risks are assessed. Selecting energy-efficient cloud infrastructure, managing technological devices to prevent e-waste generation, and establishing ethical standards for the use of AI are all included in governance that supports sustainability (Corbett, 2023). This governance not only regulates the effective use of technology but also ensures that technology does not have negative environmental and social impacts.

Organizational learning capability also determines a company's agility in adapting to changes in regulations, technology, and market needs. Argyris & Schön (1978) have shown that organizations with double-loop learning tend to question fundamental assumptions and create more radical innovations—a key characteristic of green innovation. In the digital context, learning capability helps companies keep pace with developments such as AI-based renewable energy or blockchain-based carbon monitoring systems. Thus, organizational capability functions as a "translator" between the leader's vision and the implementation of sustainable digital transformation.

3. Digital Technology as an Enabler of Sustainability and Green Innovation

Digital technology plays a crucial role as an enabler in accelerating green innovation and achieving sustainability goals. In the technology management literature, digitalization has been identified as a key driver of increased resource efficiency, waste reduction, and the transformation of business models toward a circular economy (Bai et al., 2022; George, Merrill & Schillebeeckx, 2020). Digital technology not only enables increased productivity but also provides an information infrastructure that can monitor, predict, and optimize environmental impacts in real time.

3.1 IoT as a Driver of Transparency and Environmental Efficiency

The Internet of Things (IoT) is one of the technologies that contributes most to environmental sustainability. IoT enables sensors to be installed in buildings, machinery, energy networks, and agricultural ecosystems to monitor energy consumption, detect leaks, or measure waste. A study by Kiel et al. (2017) showed that integrating IoT into production processes can reduce material and energy consumption through predictive maintenance systems, which prevent machine breakdowns and extend the lifespan of industrial assets. IoT applications in smart grids also enable more efficient energy distribution that is responsive to demand fluctuations, ultimately reducing reliance on fossil fuel-based power plants (Gungor et al., 2013). In the agricultural sector, the IoT-based precision agriculture concept has been shown to significantly reduce water and fertilizer use through micro-local monitoring of soil moisture and weather (Wolfert et al., 2017). Thus, IoT plays a role not only as a monitoring tool but also as a data-driven decision-making mechanism that directly reduces a company's operational carbon footprint.

3.2 Big Data Analytics as a Driver for Optimization and Waste Reduction

Big data analytics enables organizations to extract energy consumption patterns, optimize logistics routes, and predict environmental anomalies. In the context of the logistics industry, a study by McKinnon (2018) showed that big data analytics can reduce logistics emissions by 10–20% through route and load capacity optimization. Big data is also used to monitor production and consumption patterns in renewable energy systems. For example, the combination of weather data, energy demand, and storage levels allows renewable energy grids to be more stable and efficient (Lund et al., 2015). Furthermore, data analytics in

manufacturing can detect the most energy-intensive process stages, enabling more targeted efficiency interventions. In the circular economy sector, big data analytics is used to map material flows and identify opportunities for recycling or reuse (Bai et al., 2022). This means that big data is not only an optimization tool but also a strategic component in the design of sustainable production systems.

3.3 Artificial Intelligence (AI) as an Engine for Green Innovation

Artificial Intelligence (AI) is becoming a key driver for sustainability at the industrial and global levels. AI enables complex analysis of operational and environmental data, predicts energy consumption, and optimizes manufacturing processes. According to the Global e-Sustainability Initiative (GeSI, 2021) report, AI technology has the potential to contribute up to 4% to global emissions reductions by 2030, primarily through intelligent energy systems, automated transportation, and building energy management. A recent study by Li et al. (2024) showed that AI enables companies to increase operational efficiency by 15–30% by reducing energy use in high-intensity production systems. In the context of smart cities, AI is being used to optimize streetlights, waste management, and public transportation, collectively reducing city energy consumption. AI is also being used in early deforestation detection, biodiversity monitoring, and environmental disaster prediction through satellite imagery analysis (Rolnick et al., 2022). Thus, AI is no longer just an industrial tool but also a crucial instrument in global efforts to protect ecosystems.

3.4 Blockchain for Transparency and Sustainable Supply Chains

Blockchain plays a significant role in creating more transparent supply chains. Saberi et al. (2019) demonstrated that blockchain can ensure the integrity of environmental data, the authenticity of raw materials, and ESG (Environmental, Social, Governance) compliance. In the textile industry, blockchain is used to track the origin of cotton, the use of chemical dyes, and the product distribution process to minimize the risk of greenwashing. In the food industry, companies use blockchain to track the use of pesticides, water, and fuel in distribution, increasing environmental accountability (Ferrag et al., 2020). In the mining sector, blockchain ensures that minerals (such as cobalt or rare earth elements) are sourced ethically and sustainably—a crucial issue in the production of electric vehicle batteries. Thus, blockchain strengthens consumer, regulator, and investor confidence in a product's sustainability claims.

3.5 Cloud Computing and Energy-Efficient Digital Infrastructure

Cloud computing provides a low-energy alternative to traditional data centers. The cloud computing model enables server consolidation, hardware utilization optimization, and large-scale renewable energy adoption. According to Accenture (2020), cloud migration can reduce a company's carbon emissions by up to 84% if implemented on optimized, renewable energy-based infrastructure. However, data center energy consumption remains a challenge. Analysis by Jones (2018) and a report by the International Energy Agency (IEA, 2021) indicate that data centers and digital networks account for 1% of global electricity consumption, and this figure could increase sharply due to the development of generative AI and large models that require high computing power.

Therefore, digital technology must be managed with appropriate energy strategies, such as:

- selecting renewable energy-based cloud providers (e.g., AWS, Google Cloud, Microsoft Azure, which are committed to 100% renewable energy),
- using energy-efficient data centers,
- implementing algorithmic efficiency optimization (to reduce the carbon footprint of AI),
- managing the device lifecycle to reduce e-waste (Baldé et al., 2020).

4. Green Innovation as a Result of the Integration of Leadership, Capabilities, and Technology

Green innovation is a core element in the transformation towards a green and digital economy. Academic literature positions green innovation as the outcome of the integration of three key components: digital leadership, organizational capabilities, and digital technology (Zhang, Khan & Lee, 2022; Del Río et al., 2016). These three factors work synergistically to encourage organizations to create products, processes, or business models oriented towards sustainability and resource efficiency. Therefore, green innovation is not simply the result of the use of advanced technology, but rather the result of a comprehensive strategy that integrates leadership vision, organizational readiness, and the appropriate use of technology.

4.1 Digital Leadership as a Catalyst for the Integration of Sustainability and Technology

Digital leadership plays a central role in guiding organizations towards green innovation. Digital leaders are decision-makers who ensure that digital technology is used not only to improve business efficiency but also to support the sustainability agenda (Susanti et al., 2023). Digital leaders navigate two imperatives simultaneously:

- The technology imperative, which assesses the potential and risks of new technologies,
- The sustainability imperative, which prioritizes environmental impact in every digital decision.

A study by Karimi & Walter (2016) shows that digital transformation cannot be effective without strategic direction from leaders with a long-term technological vision. In the context of sustainability, digital leaders influence the adoption of green solutions such as low-carbon cloud computing, energy-efficient AI models, and circular economy technologies. Furthermore, digital leadership plays a role in creating an organizational culture that supports the exploration of green technologies, for example by encouraging an innovation mindset, cross-functional collaboration, and digital upskilling employees (Haffke, Kalgovas & Benlian, 2017). Without leaders who explicitly integrate digitalization and sustainability, digital technology will become merely a tool for operational efficiency, not an innovation that generates environmental value.

4.2 Organizational Capabilities as the Foundation for Green Innovation Implementation

Organizational capabilities, including digital capabilities, environmental capabilities, absorptive capacity, and dynamic capabilities, are critical factors in ensuring digital technology can be transformed into green innovation. According to dynamic capabilities theory, organizations that are able to integrate, build, and reconfigure resources are better able to respond to environmental and technological changes (Teece, 2018).

There are three main capabilities that support green innovation:

- Digital Capabilities, related to an organization's ability to adopt, integrate, and scale digital technologies. Research by Chanias & Hess (2016) concluded that companies with strong digital capabilities are more easily able to develop low-carbon production processes because they understand how technology works and how to optimize its use.
- Environmental Capabilities, encompassing an organization's ability to systematically manage energy, waste, and emissions. Strengthening these capabilities encourages companies to identify areas that can be optimized through digital technology, such as energy for HVAC systems, transportation, or supply chains (Russo & Fouts, 1997).
- Innovation and Absorptive Capacity, plays a role in an organization's ability to absorb and apply new knowledge. Cohen & Levinthal (1990) emphasized that companies with

high knowledge absorptive capacity are more quickly able to utilize new technologies for innovation, including green innovation.

These capabilities complement each other and form the foundation for digital technologies not only to be adopted, but to truly produce valuable green innovations.

4.3 Digital Technology as a Driver of Green Innovation

Digital technology provides the technical mechanisms for designing, testing, and implementing green innovations. The OECD (2019) emphasizes that digitalization accelerates green innovation through three main functions:

- Monitoring: real-time monitoring of energy use, waste, water, and emissions.
- Optimization: optimizing energy-intensive operational processes.
- Simulation: modeling the environmental impact of product design and production decisions.

One of the most significant technologies in green innovation is digital twins, which are virtual representations of physical products or systems. According to Ribeiro et al. (2022), digital twins enable companies to simulate energy consumption, predict machine wear, and detect process waste without the need for physical testing. This not only reduces costs but also reduces material and energy use.

Furthermore, AI is being used to design low-carbon manufacturing processes, optimize energy mixes, and predict machine behavior; IoT is being utilized to monitor moisture and nutrient levels in precision agriculture, thereby reducing water and fertilizer use (Wolfert et al., 2017). Blockchain strengthens the integrity of sustainability data by ensuring supply chain transparency and preventing greenwashing (Saberi et al., 2019). Thus, digital technology provides the technical capability to objectively create and measure the impact of green innovation.

4.4 Synergy of Digital Leadership, Organizational Capabilities, and Technology in Driving Green Innovation

Green innovation emerges when digital leadership establishes a clear vision, the organization possesses adequate capabilities, and digital technology is used to achieve sustainability goals. Digital leadership establishes an integrated sustainability and digitalization strategy (digital-sustainability alignment). This ensures technology is implemented not only for efficiency but also for long-term emission reductions (George et al., 2020). Meanwhile, organizational capabilities ensure that the green innovation vision can be translated into concrete implementation. Digital leaders often mobilize training, create cross-functional teams, and collaborate with technology partners. Digital technology becomes an operational tool for: (1) detecting inefficiencies, (2) simulating improvements, (3) optimizing energy use, (4) designing circular products, and (5) ensuring environmental compliance. Recent empirical studies also show that the stronger the integration between digital technology and organizational capabilities, the higher the level of green innovation in a company (Zhang et al., 2022; Saunila, Ukko & Rantala, 2018).

4.5 Green Innovation as a Synergistic Output and Competitive Advantage

When this integration is effective, green innovation emerges in the form of products, processes, and business models. An OECD study (2019) confirms that green innovation creates new competitive advantages through:

- reduced energy costs,
- increased operational efficiency,
- enhanced ESG reputation,
- improved regulatory compliance, and
- access to new, more environmentally conscious markets.

At the macro level, green innovation contributes to green economic development, mitigates climate change, and enhances the resilience of global supply chains (European Commission, 2020).

5. Ecosystem Collaboration as the Foundation of Sustainable Digital Transformation

Sustainable digital transformation cannot be achieved through the efforts of individual organizations but requires cross-sector collaboration involving actors from government, industry, academia, civil society, and international organizations. In the innovation literature, the concept of cross-sector collaboration is comprehensively explained by Carayannis and Campbell (2022) through the Quintuple Helix Innovation model, which emphasizes that sustainable innovation is the result of dynamic interactions between five subsystems: government, industry, academia, civil society, and the natural environment. This model expands the previous Triple and Quadruple Helix frameworks to include environmental aspects, thus emphasizing that digital innovation must align with ecological sustainability goals.

In the context of sustainable digital transformation, ecosystem collaboration is necessary due to the increasing complexity of the challenges facing organizations. Companies require access to green technologies, interoperability standards, energy regulations, and scientific knowledge that often resides outside organizational boundaries. For example, the European Green Digital Coalition (European Commission, 2021) is an example of a major collaboration between global technology companies and EU governments to develop standards for measuring digital carbon footprints and promote low-carbon digital solutions. International initiatives such as Smart Sustainable Cities, led by the International Telecommunication Union (ITU, 2021), also encourage cooperation between cities, technology providers, and standards bodies to develop interoperability frameworks for energy, transport, waste, and urban data management.

Collaboration within the ecosystem also facilitates joint research and innovation. Many industries are now collaborating with universities to develop AI for Sustainability applications, such as data-driven energy demand predictions or forest carbon mapping using satellite imagery (Rolnick et al., 2022). Meanwhile, startups play a crucial role in accelerating the adoption of circular economy business models, including product-as-a-service platforms, reverse logistics, and material traceability, which require a high degree of digital integration (Geissdoerfer et al., 2020). Without cross-actor collaboration, these innovations will struggle to achieve the scale and impact necessary for systemic change.

From a leadership perspective, digital leaders act as ecosystem orchestrators, connecting organizations with relevant partners to strengthen green innovation. This aligns with the findings of Nambisan et al. (2018), who stated that digital innovation is most successful when leaders are able to manage collaborative platforms, build trust between stakeholders, and ensure the smooth flow of data and knowledge. Digital leaders also facilitate the co-creation of solutions with technology partners and regulators, including in the development of renewable energy standards, digital impact measurement, and the implementation of low-carbon technologies such as the green cloud and energy-efficient AI.

Thus, ecosystem collaboration not only supports sustainable digital transformation but also strengthens organizations' ability to access resources, accelerate green innovation, and

increase resilience in the face of global environmental challenges. A robust innovation ecosystem enables digital sustainability to occur systematically, coordinated, and with long-term impact.

6. Challenges and Paradoxes in Sustainable Digital Transformation

While sustainable digital transformation holds significant potential for driving energy efficiency, emissions reduction, and green innovation, its implementation is not without challenges and paradoxes. These challenges encompass interconnected technological, social, economic, and ethical aspects, often creating structural barriers for organizations and governments in integrating digital and sustainability agendas. From a technological perspective, digital energy consumption is a prominent issue. Digital infrastructure, including data centers, communication networks, and computing devices, requires significant amounts of energy, which can actually increase carbon emissions if not powered by renewable energy.

According to the International Energy Agency (IEA, 2021), global data centers consume approximately 1% of the world's electricity, and this figure is expected to increase with the growth of generative AI and the adoption of cloud computing. A study by Strubell et al. (2019) showed that training a single large AI model can generate significant emissions, creating a paradox when a technology promoted as a sustainable solution actually increases the carbon footprint. Beyond energy, cybersecurity risks are a major challenge. Digital transformation expands the attack surface, creating new vulnerabilities in IoT-based energy, logistics, and manufacturing systems. The ENISA (2022) report confirms that threats to smart grids and IoT-based industrial systems are increasing annually, and security failures can have significant impacts on public infrastructure and the environment.

Another challenge is the high initial investment requirements. Integrating technologies such as IoT, AI, blockchain, and digital twins requires significant capital, especially for small and medium-sized enterprises (SMEs). This can create an adoption gap and slow down sustainable digital transformation in traditional sectors. Socially, digitalization can deepen the digital divide between those with and without access to technology. This digital divide is a major obstacle to social sustainability, especially in developing countries. According to the ITU (2022) report, approximately 2.7 billion people worldwide remain without internet access, preventing them from utilizing digital services for education, energy, or public services. Furthermore, the adoption of automation and AI raises concerns about the replacement of human labor. Frey and Osborne (2017) indicate that approximately 47% of jobs in the United States are at high risk of automation. While digitalization can create new jobs, the skills shift toward high-tech jobs can widen the gap between skilled and unskilled labor.

Ethically, the use of AI poses the risk of algorithmic bias, which can have far-reaching impacts on sustainability-based decisions. Inaccurate AI models can result in incorrect energy predictions, inefficient resource allocation, or errors in emissions monitoring. A study by Buolamwini & Gebru (2018) showed that facial recognition algorithms exhibit significant bias against certain racial groups, indicating that bias may also emerge in sustainability algorithms if not comprehensively tested. Therefore, strong digital governance is needed to ensure the ethical and responsible use of technology. The Principles for Responsible AI recommended by the OECD (2021) serve as an important reference for ensuring transparency, accountability, and fairness in the use of AI.

7. Integrating Digital Leadership, Capabilities, and Green Innovation Towards Sustainable Digital Transformation

The integration of digital leadership, organizational capabilities, and green innovation is the key foundation for achieving sustainable digital transformation. Innovation management

literature shows that successful transformation depends not only on technology adoption, but also on an organization's ability to align its strategic vision, internal structure, and innovation processes (Teece, 2018; Warner & Wäger, 2019). In the context of sustainability, this alignment becomes even more crucial as organizations face simultaneous pressures to digitally transform and meet environmental, social, and governance (ESG) demands. Digital leadership serves as a key driver, creating a long-term vision of technology's role in achieving sustainability. Effective digital leaders focus not only on technology as an efficiency tool but also see it as a driver of systemic change that can reduce emissions, increase social inclusiveness, and create new value for society (Kiron & Unruh, 2018). These leaders foster an organizational culture that supports exploration, experimentation, and cross-functional collaboration—essential elements of green innovation. This aligns with the findings of Haffke, Kalgovas, & Benlian (2017), who emphasized that digital transformation is successful when leaders can play a dual role: as drivers of digitalization and agents of organizational change.

Meanwhile, organizational capabilities serve as the operational foundation that determines whether the leadership vision can be realized. The concept of dynamic capabilities (Teece, 2018) explains that organizations must be able to identify technological opportunities, absorb new knowledge, and reconfigure processes to support sustainable strategies. Digital capabilities—including data analytics capabilities, IoT integration, and AI governance—help organizations leverage relevant technologies, while environmental capabilities enable organizations to respond to needs for energy efficiency, waste reduction, and regulatory compliance (Russo & Fouts, 1997). A study by Zhang, Khan, & Lee (2022) also showed that the combination of digital and green capabilities significantly increases the level of green innovation across various industrial sectors.

At this point, green innovation becomes the outcome of the complex interaction between leadership and organizational capabilities. Digital technologies such as AI, big data, blockchain, and digital twins offer opportunities to design more efficient production processes, optimize low-carbon supply chains, and create circular economy business models (George, Merrill & Schillebeeckx, 2020; Ribeiro et al., 2022). However, green innovation can only be realized if organizations possess strategic capabilities, a learning culture, and transformational leadership capable of directing technology toward sustainability goals.

Overall, sustainable digital transformation is a multidimensional process that requires structural, cultural, and strategic changes. It is not enough for organizations to simply adopt technology; they must integrate it into a broader sustainability vision. Digital leaders must understand both technological dynamics and environmental challenges, while organizations must build long-term capabilities to adapt and innovate. With a strong integration of green leadership, capabilities, and innovation, organizations can achieve sustainability while increasing competitiveness in the digital and green economy era.

Conclusion

This article emphasizes that leading sustainable digital transformation is a complex and multidimensional strategic process, which can only succeed if organizations are able to integrate digital leadership, organizational capabilities, digital technology, and green innovation within a mutually reinforcing framework. Digital leadership has proven to be a key actor providing direction, vision, and legitimacy for sustainability-oriented digital transformation. Digital leaders not only drive technology adoption but also establish a strategic sense that digitalization must have a positive impact on the environment, society, and the green economy. Organizational capabilities act as a driving force that translates this vision into concrete practices. Digital capabilities, an adaptive organizational culture, digital governance, and the ability to learn together enable organizations to respond to technological ambiguity

while integrating sustainability goals into their digital strategies. In this context, organizational capabilities act as a mediator, strengthening the relationship between digital leadership and green innovation.

Digital technologies such as AI, IoT, big data analytics, blockchain, and the cloud play a key role as enablers, enabling energy efficiency, carbon emission monitoring, value chain transparency, and the creation of greener business processes. However, digital technology is not without risks, as paradoxes of digitalization such as increased data center energy consumption, digital inequality, and the ethical risks of AI can hinder sustainability efforts if strong governance is not implemented. Green innovation ultimately emerges as a logical outcome of the integration of all these factors. Organizations led by visionary digital leaders, with the right capabilities, will be able to leverage technology to create products, processes, and business models that support a green economy and circularity. Cross-ecosystem collaboration—involving government, industry, academia, and communities—further strengthens the transformation process.

Overall, this article demonstrates that sustainable digital transformation is not just a technological agenda, but also a strategic one that demands changes in organizational mindsets, structures, capabilities, and ecosystems. Its success lies in the organization's ability to embrace digitalization without neglecting long-term environmental, social, and economic responsibilities.

4.2 Theoretical Recommendations and Research Development

- Future research studies can expand the model by incorporating new variables such as digital ethics, ecological intelligence, or AI literacy within the organization.
- Future studies could integrate analysis at the individual level (leaders' digital competencies), the organizational level (capabilities and culture), and the ecosystem level (public-private collaboration).
- Digital transformation is a long-term process; therefore, longitudinal research is needed to understand the dynamics of organizational capability change and its impact on green innovation.
- Further research is needed on the paradox of digital energy consumption, the environmental impact of IT hardware, and the ethical dilemmas of AI.

4.3 Strategic Recommendations for Organizations

- Organizations need to build the capacity of leaders who can see the link between technology, business operations, and environmental impact. Digital-green leadership training programs are highly recommended.
- Focus should be placed on improving digital literacy, analytical capabilities, data governance, and organizational learning mechanisms to ensure sustainability-driven digital readiness.
- Organizations should adopt renewable energy-based clouds, use energy-efficient devices, optimize AI algorithms, and manage the recycling of technological devices.
- Every digital project should be measured not only in terms of financial ROI, but also in terms of carbon emissions, resource efficiency, and social impact. The use of digital sustainability dashboards is highly recommended.
- Organizations should leverage IoT for energy monitoring, AI for process efficiency, blockchain for supply chain transparency, and digital twins to optimize sustainable manufacturing processes.
- Collaboration with governments, universities, green technology startups, and international institutions can accelerate the development of green innovations while reducing costs and risks.

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