

Generative Artificial Intelligence for Sustainable Digital Business Transformation

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ABSTRACT

The rapid advancement of digital technology and environmental challenges has encouraged organizations to adopt innovative approaches to achieve sustainable business transformation. This study investigates the role of Generative Artificial Intelligence in supporting sustainable digital business transformation by examining how AI driven systems enhance operational efficiency, innovation capability, decision making quality, and environmental sustainability. The background of this research is based on the increasing need for businesses to integrate intelligent technologies with sustainable practices in order to remain competitive and resilient in the digital era. **The objective** of this study is to analyze the contribution of Generative Artificial Intelligence toward sustainable business development and digital transformation strategies. **The method** employed in this research uses a qualitative literature review approach by analyzing recent scholarly articles, industry reports, and technological studies related to artificial intelligence, sustainability, and digital business transformation. **The results indicate** that Generative Artificial Intelligence significantly contributes to improving business adaptability, automating operational processes, reducing resource consumption, and encouraging eco friendly innovation. In addition, AI technologies support organizations in developing data driven strategies that strengthen long term sustainability and resilience. **The conclusion** of this study emphasizes that Generative Artificial Intelligence has become an important driver in creating intelligent, innovative, and sustainable digital business ecosystems capable of addressing future environmental and technological challenges while maintaining organizational competitiveness in the global market.

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1. INTRODUCTION

The acceleration of digital transformation has significantly reshaped the global business environment, encouraging organizations to adopt advanced technologies that enhance efficiency, innovation, and long-term sustainability. Among these technologies, Generative Artificial Intelligence (GenAI) has emerged as a transformative innovation capable of generating content, supporting human creativity, analyzing large-scale data, and enabling adaptive problem-solving. Unlike conventional AI, which primarily focuses on automation and prediction, GenAI offers broader capabilities that support strategic decision-making and business innovation. Its rapid adoption has attracted growing attention from companies, startups, and governments seeking solutions to complex economic and environmental challenges. Simultaneously, increasing concerns regarding climate

change, resource depletion, and environmental degradation have intensified the demand for sustainable digital business transformation. Organizations are now evaluated not only by financial performance but also by their environmental responsibility, social contribution, and resilience in dynamic markets. Consequently, businesses are integrating sustainability principles into digital transformation strategies through intelligent technologies that optimize resource utilization, reduce operational waste, and improve energy efficiency [1]. Supported by cloud computing, big data analytics, the Internet of Things (IoT), and machine learning, GenAI enables predictive analytics, smart resource management, automated customer interactions, and environmentally responsible operational planning. These capabilities allow organizations to improve productivity while balancing economic growth and ecological sustainability.

The growing adoption of GenAI across industries demonstrates its potential to support sustainable innovation and organizational resilience. In manufacturing, AI technologies optimize production processes, reduce carbon emissions, and improve supply chain efficiency [2]. In service sectors, GenAI enhances customer engagement, personalized experiences, and data-driven decision-making. Startups and digital businesses increasingly utilize AI-powered solutions to strengthen innovation capability, accelerate market adaptation, and develop scalable business models [3]. However, the implementation of GenAI also presents challenges related to technological readiness, cybersecurity, ethical concerns, regulatory uncertainty, and organizational capability gaps, particularly among small and medium-sized enterprises. Previous studies have generally examined artificial intelligence, digital transformation, and sustainability as separate research streams [4]. AI research primarily focuses on technology adoption, automation, and productivity, while digital transformation studies emphasize organizational digitalization and sustainability research concentrates on environmental performance and ESG practices. Therefore, the strategic integration of these three domains through GenAI remains under-explored [5]. This study addresses this gap by positioning GenAI not only as an automation technology but also as a strategic enabler that simultaneously enhances innovation capability, operational efficiency, organizational resilience, and environmental sustainability. Furthermore, the study integrates Digital Transformation, Dynamic Capability Theory, and Sustainable Innovation into a unified conceptual framework, providing a comprehensive perspective on how GenAI supports digital competitiveness, long-term resilience, and sustainable value creation.

This study aims to analyze the role of GenAI in sustainable digital business transformation by examining its contributions to innovation development, operational efficiency, environmental sustainability, and organizational resilience. Using a qualitative literature review approach, the study evaluates recent scholarly publications, industry reports, and technological studies related to AI, sustainability, and digital transformation. The findings are expected to contribute theoretically by advancing understanding of the relationship between GenAI and sustainable digital business transformation, and practically by providing guidance for business managers, startup founders, policymakers, and technology developers in implementing responsible AI strategies. This study also aligns with the United Nations Sustainable Development Goals (SDGs). GenAI supports SDG 9 (Industry, Innovation and Infrastructure) by accelerating digital innovation and strengthening intelligent infrastructure. It contributes to SDG 12 (Responsible Consumption and Production) through resource optimization and waste reduction, and supports SDG 13 (Climate Action) by improving energy efficiency, enabling predictive environmental management, and reducing carbon emissions. These contributions demonstrate that sustainable digital business transformation extends beyond technological advancement by creating long-term economic, environmental, and societal value [6]. Consequently, GenAI is expected to play a pivotal role in enabling organizations to achieve operational excellence, innovation-driven growth, and environmental responsibility in the digital era.

2. LITERATURE REVIEW

2.1. Generative Artificial Intelligence in Digital Business

Generative Artificial Intelligence (GenAI) has emerged as a transformative technology in the digital business era due to its ability to generate content, automate communication, and support intelligent decision-making [7]. Unlike conventional AI systems that primarily focus on prediction and automation, GenAI leverages Large Language Models (LLMs), transformer architectures, deep learning, and Natural Language Processing (NLP) to understand context, generate human-like responses, and continuously improve outputs through iterative learning [8]. These capabilities enable GenAI to process structured and unstructured data, identify semantic relationships, and provide adaptive recommendations for complex business decisions [9].

Beyond content generation, GenAI incorporates intelligent automation through workflow orchestration, retrieval-augmented generation (RAG), predictive analytics, and human-in-the-loop feedback mechanisms. These technologies allow organizations to automate knowledge-intensive tasks while maintaining contextual accuracy and continuous learning. Rather than replacing human expertise, GenAI enhances managerial decision-making by delivering real-time insights, intelligent recommendations, and process optimization across functions such as marketing, customer service, product development, supply chain management, and strategic planning [10]. Consequently, GenAI should be viewed not only as a productivity-enhancing technology but also as a strategic cognitive system that integrates data analysis, knowledge generation, and autonomous decision support. These capabilities contribute to more adaptive, resilient, and sustainability-oriented digital business ecosystems while improving innovation and operational performance. Recent studies highlight GenAI's role in business model innovation, digital entrepreneurship, innovation capability, and digital transformation [11].

From the perspective of Dynamic Capability Theory (Teece, 2007), GenAI strengthens the organizational capabilities of sensing, seizing, and reconfiguring. GenAI enhances sensing through AI-driven analytics and predictive intelligence that identify market trends, customer needs, sustainability challenges, and emerging opportunities. It supports seizing through intelligent content generation, scenario simulation, and data-driven strategic planning that facilitate innovation and digital business development. Furthermore, GenAI enables reconfiguring through intelligent automation, workflow optimization, knowledge management, and continuous learning, allowing organizations to redesign processes, optimize resources, and strengthen resilience. Therefore, Dynamic Capability Theory provides a strong foundation for understanding how GenAI evolves beyond operational automation into a strategic capability that supports sustainable digital business transformation, innovation capability, environmental sustainability, and long-term organizational resilience.

2.2. Sustainable Digital Business Transformation

Sustainable digital business transformation refers to the integration of digital technologies with sustainability principles to achieve economic growth, operational efficiency, and environmental responsibility simultaneously [12]. Organizations are increasingly adopting digital technologies such as Artificial Intelligence, cloud computing, big data analytics, and Internet of Things systems to improve business sustainability and resilience [13]. Digital transformation not only improves organizational performance but also supports environmentally responsible business operations through efficient resource utilization and waste reduction [14]. The development of sustainable digital transformation strategies has become essential due to increasing environmental challenges and market uncertainty. Intelligent technologies enable businesses to optimize operational activities, improve energy efficiency, and support sustainable innovation practices. Furthermore, organizations that successfully integrate sustainability with digital transformation are more capable of maintaining long term competitiveness and resilience in the evolving global business environment [15].

2.3. Artificial Intelligence and Sustainable Innovation

Artificial Intelligence plays a significant role in supporting sustainable innovation by improving operational efficiency, predictive capability, and intelligent resource management [16]. Sustainable innovation refers to the development of products, services, and business processes that generate economic value while minimizing environmental impact. AI driven technologies support organizations in creating adaptive and environmentally responsible innovation strategies through data analysis, predictive modeling, and automation systems. In modern digital ecosystems, Artificial Intelligence contributes to sustainable innovation by enabling organizations to optimize supply chains, reduce operational waste, and improve energy management. AI technologies also facilitate real time analysis that helps businesses identify sustainability risks and opportunities more effectively. Consequently, Artificial Intelligence has become an important enabler of environmentally conscious innovation and sustainable business development.

2.4. The Role of Artificial Intelligence in Environmental Sustainability

Environmental sustainability has become a critical global concern due to climate change, environmental degradation, and resource scarcity [17]. Artificial Intelligence (AI) offers significant opportunities to support environmental protection, climate adaptation, and sustainable resource management through predictive analytics and intelligent monitoring systems [18]. AI-driven technologies enable organizations to analyze environmental data more effectively, improve energy efficiency, reduce carbon emissions, and develop proactive sustainability strategies [19]. Furthermore, AI is increasingly applied in smart cities, renewable energy

management, sustainable agriculture, and green logistics, demonstrating its important role in advancing global sustainability goals and environmentally sustainable digital ecosystems [20].

2.5. Challenges of Generative Artificial Intelligence Adoption

Despite the benefits of Generative Artificial Intelligence, organizations also face several challenges related to technological implementation, ethical governance, and sustainability concerns [21]. One of the primary challenges is the lack of technological readiness and skilled human resources required for implementing advanced AI systems. Many businesses, particularly small and medium enterprises, experience limitations in infrastructure capability, financial investment, and digital expertise [22]. Ethical issues such as algorithm bias, data privacy, transparency, and misinformation also remain major concerns in the implementation of GenAI technologies [21]. In addition, large scale AI systems require significant computational power and energy consumption, which may create environmental sustainability challenges if not managed responsibly. Several previous studies emphasize the positive impact of Generative Artificial Intelligence on operational efficiency and digital innovation [23]. However, other researchers argue that excessive dependence on AI systems may increase ethical risks, cybersecurity vulnerability, and energy consumption associated with large scale computational infrastructure. These contrasting perspectives indicate that the implementation of Generative Artificial Intelligence requires balanced governance strategies that align technological advancement with sustainability objectives [24]. Therefore, organizations must develop responsible AI governance frameworks to ensure that technological innovation aligns with sustainability principles and ethical standards.

3. RESEARCH METHOD

This study employed a qualitative literature review approach to examine the role of Generative Artificial Intelligence (GenAI) in supporting sustainable digital business transformation. Secondary data were collected from four major academic databases, namely Scopus, ScienceDirect, SpringerLink, and Google Scholar [25]. To ensure comprehensive coverage of relevant studies, the literature search utilized combinations of the following keywords and search strings: ("Generative Artificial Intelligence" OR "GenAI") AND ("Digital Business" OR "Digital Transformation") AND ("Sustainability" OR "Sustainable Business") AND ("Innovation Capability" OR "Organizational Resilience"). The search was limited to publications published between 2022 and 2026 to capture the most recent developments and emerging trends in GenAI research. The literature selection process followed a systematic multi-stage screening procedure to ensure the quality and relevance of the reviewed studies. Initially, all records retrieved from the selected databases were compiled into a single dataset, and duplicate publications were removed. Subsequently, the titles and abstracts of the remaining studies were screened to assess their relevance to the research objectives [26]. Articles that met the preliminary screening criteria were then subjected to a full-text review. During this stage, studies were evaluated based on predefined inclusion and exclusion criteria. The inclusion criteria consisted of peer-reviewed journal articles, conference proceedings, and industry reports published in English that explicitly discussed Generative Artificial Intelligence, digital transformation, sustainability, innovation capability, or organizational resilience within business contexts. Conversely, the exclusion criteria included duplicate records, non-English publications, editorials, opinion papers lacking empirical or academic evidence, studies published before 2022, and articles that did not directly examine the relationship between GenAI and sustainable digital business transformation. This structured screening process ensured that only high-quality and relevant sources were included in the final analysis. To ensure methodological rigor, a quality assessment was conducted by evaluating each study according to four criteria:

- Publication in reputable academic sources,
- Relevance to the research objectives,
- Methodological clarity, and
- Contribution to understanding the role of GenAI in sustainable digital business transformation.

Only studies meeting these quality standards were retained, resulting in a final dataset of 45 publications. The selected literature was then analyzed using qualitative content analysis to identify recurring themes, conceptual relationships, and emerging trends related to operational efficiency, sustainable innovation, environmental sustainability, and organizational resilience within digital business ecosystems.

Table 1. Research Design Components

Research Component	Description	Purpose
Research Method	Qualitative Literature Review	To examine the role of Generative Artificial Intelligence in sustainable digital business transformation.
Data Type	Secondary Data	To obtain relevant theoretical and empirical information from academic sources.
Research Database	Scopus, ScienceDirect, SpringerLink, and Google Scholar	To collect credible and recent scholarly publications.
Publication Period	2022–2026	To ensure the relevance and recency of the analyzed literature.
Number of Articles	Approximately 45 Articles	To provide sufficient academic evidence for the analysis.
Inclusion Criteria	Peer-reviewed journal articles, conference proceedings, and industrial reports related to AI, sustainability, and digital transformation	To maintain the relevance and quality of the selected studies.
Exclusion Criteria	Duplicated, unrelated, and irrelevant publications	To ensure consistency and accuracy in the analysis.
Research Focus	Generative AI, Sustainability, Innovation Capability, and Organizational Resilience	To analyze the contribution of AI toward sustainable digital transformation.
Analysis Technique	Qualitative Content Analysis	To identify conceptual relationships, major themes, and emerging trends.

Table 1 presents the main components used in the research design to support the analysis of Generative Artificial Intelligence in sustainable digital business transformation. The research method applies a qualitative literature review approach to examine theoretical and empirical findings from previous studies related to artificial intelligence, sustainability, and digital innovation. Secondary data were utilized as the primary source of information because the analysis relied on academic journals, conference papers, and industry reports published in reputable databases. The main focus of the analysis centers on the relationship between Generative Artificial Intelligence, sustainable innovation, and digital business transformation in modern organizations. Furthermore, content analysis techniques were employed to identify important themes, compare findings from previous literature, and interpret how intelligent technologies contribute to operational efficiency, environmental sustainability, and organizational resilience in the digital era.

Table 2. Data Analysis Process

Analysis Stage	Activity
Literature Selection	Selecting relevant academic sources
Data Categorization	Grouping studies based on themes
Content Analysis	Identifying concepts and findings
Interpretation	Analyzing the contribution of AI
Conclusion Drawing	Synthesizing overall research insights

Table 2 Data Analysis Process explains the stages used to analyze the collected literature related to Generative Artificial Intelligence and sustainable digital business transformation. The process began with

literature selection by identifying relevant and credible academic sources. The selected studies were then categorized into themes such as AI adoption, sustainability, digital transformation, and innovation capability. Content analysis was conducted to examine important concepts and findings from previous studies, followed by interpretation to understand the contribution of Generative Artificial Intelligence toward operational efficiency, sustainable innovation, environmental management, and organizational resilience. Finally, the findings were synthesized systematically to provide comprehensive insights into the role of intelligent technologies in sustainable digital business transformation.

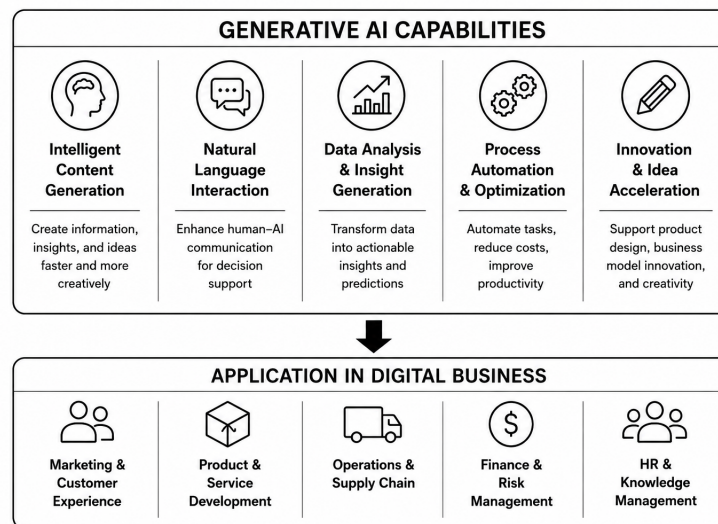


Figure 1. The Role of Generative Artificial Intelligence in Sustainable Digital Business

Figure 1 illustrates the conceptual framework of Generative Artificial Intelligence capabilities and their applications in supporting sustainable digital business transformation. The framework demonstrates how AI driven capabilities such as intelligent content generation, data analysis, process automation, and innovation acceleration contribute to various digital business functions including marketing, product development, operations, finance, and human resource management.

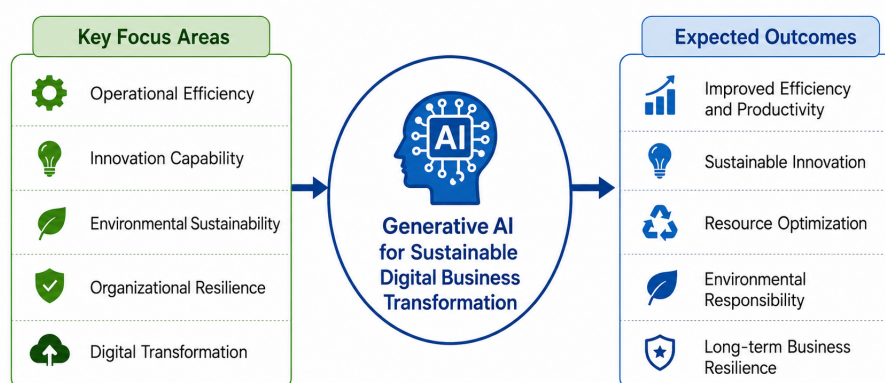


Figure 2. The Role of Generative Artificial Intelligence in Sustainable Digital Business

Figure 2 illustrates the conceptual relationship between Generative Artificial Intelligence (GenAI), the key organizational focus areas, and the expected outcomes of sustainable digital business transformation.

The selected focus areas are positioned deliberately because they represent the primary organizational capabilities through which GenAI generates sustainable value. Operational efficiency is positioned as the foundational capability because GenAI improves workflow automation, intelligent resource allocation, and data-driven decision-making, enabling organizations to reduce costs and optimize operational performance. Innovation capability represents the organization's ability to transform AI-generated knowledge, synthetic ideation, and scenario simulation into new products, services, and digital business models that sustain competitive advantage.

Environmental sustainability is included because GenAI supports responsible resource utilization, waste reduction, energy efficiency, and predictive environmental management, contributing to more sustainable organizational practices. Organizational resilience reflects an organization's capacity to adapt to technological disruption, market uncertainty, and changing stakeholder demands through continuous learning, intelligent decision support, and adaptive business processes. Finally, digital transformation functions as the integrative capability that connects technological innovation, organizational change, and sustainability objectives into a coherent digital business strategy. Positioned at the center of the framework, GenAI acts as the strategic enabler that simultaneously strengthens these five complementary focus areas. Their interaction ultimately produces the expected outcomes of sustainable digital business transformation, including higher productivity, continuous innovation, optimized resource utilization, environmental responsibility, and long-term organizational competitiveness. This analytical explanation clarifies that the figure represents an interconnected conceptual pathway rather than a simple visual classification of organizational outcomes.

4. RESULT AND DISCUSSION

The results of the literature analysis indicate that Generative Artificial Intelligence (GenAI) plays a significant role in supporting sustainable digital business transformation by enhancing operational efficiency, innovation capability, organizational adaptability, and sustainability-oriented business practices. These findings are consistent with previous studies, which reported that GenAI improves intelligent automation, business model innovation, and digital competitiveness through data-driven decision-making and adaptive learning systems. Likewise, recent sustainability research has demonstrated that AI technologies contribute to resource optimization, energy efficiency, and environmentally responsible business operations, reinforcing the strategic role of intelligent technologies in achieving long-term sustainability. However, the findings also reveal several important differences from previous research. While many earlier studies primarily emphasized the productivity and automation benefits of AI, they often paid limited attention to the simultaneous interaction between innovation capability, organizational resilience, and environmental sustainability. Furthermore, several studies have highlighted potential drawbacks of GenAI adoption, including algorithmic bias, data privacy concerns, cybersecurity risks, high computational energy consumption, and organizational readiness challenges. These contrasting perspectives indicate that the successful implementation of GenAI depends not only on technological capability but also on responsible AI governance, digital maturity, and organizational preparedness.

The findings of this study therefore extend the existing literature by demonstrating that GenAI should be viewed as a strategic capability rather than merely an automation tool. By integrating insights from digital transformation, Dynamic Capability Theory, and sustainable innovation, this study explains how GenAI simultaneously strengthens innovation capability, operational efficiency, organizational resilience, and environmental sustainability within digital business ecosystems. This integrated perspective addresses an important research gap, as previous studies have generally examined AI adoption, digital transformation, and sustainability independently rather than as interconnected dimensions of sustainable digital business transformation. Consequently, this study provides a more comprehensive theoretical explanation of how GenAI creates long-term organizational value while supporting sustainable competitive advantage. AI supported systems enable organizations to reduce operational waste, improve energy efficiency, optimize supply chain management, and develop innovative digital products and services aligned with sustainability objectives. Furthermore, intelligent systems strengthen strategic planning and risk management processes, allowing organizations to respond more effectively to technological disruption, market uncertainty.

Despite the potential benefits of Generative Artificial Intelligence (GenAI), its implementation continues to face several technological, organizational, and environmental challenges. Some organizations lack adequate digital infrastructure, sufficient financial resources, and skilled personnel to effectively adopt advanced AI technologies. In addition, concerns regarding data protection, cybersecurity risks, algorithmic transparency, information reliability, and the potential spread of misleading content remain important considerations when

integrating GenAI into organizational activities. Beyond these organizational challenges, the environmental impact of GenAI deserves greater attention. The training and deployment of large-scale foundation models and Large Language Models (LLMs) require substantial computational power, resulting in high electricity consumption, increased carbon emissions, and intensive use of data-center infrastructure. If supported by carbon-intensive energy sources, these computational demands may partially offset the sustainability benefits generated through AI-enabled operational efficiency and resource optimization.

Therefore, achieving sustainable digital business transformation requires organizations to complement GenAI adoption with Green AI principles. This includes developing energy-efficient AI models, optimizing computational resources, utilizing renewable-energy-powered data centers, and implementing environmentally responsible AI governance throughout the AI lifecycle. By balancing technological innovation with environmentally sustainable infrastructure, organizations can maximize the long-term benefits of GenAI while minimizing its ecological footprint. These findings indicate that GenAI should not be viewed solely as a driver of innovation and operational efficiency, but also as a technology whose sustainability depends on responsible governance, energy-efficient computing, and environmentally conscious implementation. This balanced perspective provides a more comprehensive understanding of how GenAI can support sustainable digital business transformation while addressing its potential environmental trade-offs.

5. MANAGERIAL IMPLICATIONS

The findings provide several important managerial implications for organizations implementing Generative Artificial Intelligence (GenAI) in sustainable digital business transformation. Organizations should integrate GenAI into operational and strategic activities to improve efficiency, innovation capability, customer engagement, and data-driven decision-making while aligning digital transformation with sustainability objectives. For startups and SMEs, GenAI can be implemented through AI-powered conversational customer service, enabling 24/7 personalized customer support while reducing operational costs. In marketing, GenAI facilitates automated content generation for advertisements, social media campaigns, and personalized promotional materials, improving customer engagement and marketing efficiency. Furthermore, businesses can utilize GenAI for predictive demand analysis to forecast customer needs, minimize overproduction, and optimize inventory management, thereby reducing resource waste.

In operational management, GenAI supports smart resource planning by optimizing workforce allocation, production scheduling, and energy utilization based on real-time data. Within supply chain management, GenAI enables sustainable supply chain optimization by predicting procurement requirements, identifying logistics bottlenecks, reducing transportation inefficiencies, and supporting environmentally responsible sourcing decisions. These applications not only enhance business performance but also contribute to responsible resource utilization and long-term environmental sustainability. By adopting these practical applications, startups, SMEs, and digital businesses can leverage GenAI not only to improve competitiveness and innovation but also to create more resilient, resource-efficient, and sustainability-oriented business ecosystems.

In addition, organizations need to strengthen digital infrastructure, technological readiness, and workforce capability to maximize the effectiveness of AI adoption. Employee training, digital literacy development, and AI related competencies are essential to ensure that intelligent technologies can be utilized efficiently across business operations. Companies should also encourage collaborative and innovation oriented work cultures that support creativity, adaptability, and sustainable business growth. These efforts can help organizations improve operational resilience and maintain competitiveness in rapidly changing business environments. Furthermore, managers should implement responsible AI governance by ensuring data privacy, cybersecurity, transparency, and ethical AI usage within organizational systems. Businesses must also pay attention to environmentally responsible technology implementation by optimizing energy consumption and reducing operational waste associated with AI systems. By combining Generative Artificial Intelligence with sustainability oriented business strategies, organizations can achieve long term operational resilience, environmental sustainability, and innovation driven growth in the evolving digital economy.

6. CONCLUSION

This study demonstrates that Generative Artificial Intelligence (GenAI) is not only an intelligent automation technology but also a strategic enabler of sustainable digital business transformation by simultaneously enhancing operational efficiency, innovation capability, organizational resilience, and environmental sus-

tainability. The primary contribution of this study is the development of an integrated conceptual perspective that connects GenAI, digital transformation, Dynamic Capability Theory, and sustainable innovation, thereby providing a more comprehensive understanding of how intelligent technologies create long-term organizational value.

From a practical perspective, the findings provide guidance for business leaders, digital entrepreneurs, and policymakers in designing AI adoption strategies that balance technological innovation with responsible governance and sustainability objectives. However, this study is limited by its reliance on a qualitative literature review and secondary data, which may restrict the generalizability of the findings across different organizational and industrial contexts.

Future research should validate the proposed conceptual framework through quantitative, mixed-methods, or longitudinal studies using primary data from multiple industries. Further investigation is also recommended on responsible AI governance, organizational readiness, human–AI collaboration, cybersecurity, and the environmental impact of large-scale GenAI deployment to advance the understanding of sustainable digital business transformation.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: NS and NM; Methodology: NS and NA; Software: KA; Validation: NM and NA; Formal Analysis: NS and KA; Investigation: NM; Resources: NA; Data Curation: KA and NM; Writing-Original Draft Preparation: NS and KA; Writing-Review and Editing: NM and NA; Visualization: KA; All authors have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The datasets generated and analyzed during this study can be obtained from the corresponding author upon reasonable request.

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This research received no specific grant or financial assistance from any public, commercial, or non-profit funding organization.

7.5. Declaration of Conflicting Interest

The authors declare that there are no competing interests, financial conflicts, or personal relationships that could have influenced the research, interpretation, or reporting of the findings presented in this manuscript.

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