

Exploring Beyond Automation: The Role of Generative Artificial Intelligence in Accelerating Sustainable Technology Transformation for Industry 5.0

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Abstract

The world economy is influenced by two major things: technology and talent. The fusion of Generative Artificial Intelligence (GenAI), sustainable technologies, and Industry 5.0 has revolutionized the organizational change process by expanding the horizon from automation to human-centered and resilient innovation in addition to environmental responsibility. This conceptual paper analyzes the role of GenAI in facilitating the transformation of sustainable technologies using intelligent decision-making, predictive analytics, digital twins, knowledge generation, and human-AI collaboration. By leveraging recent literature from various disciplines, the study will identify the potential of GenAI in improving efficiency, resources management, circular economy initiatives, green innovation, and sustainable governance. This research paper will further analyze key challenges such as ethical AI, algorithmic accountability, cybersecurity, retraining of the workforce, regulatory considerations, and responsible technology usage. An integrated conceptual framework will be proposed connecting GenAI's capabilities with the characteristics of Industry 5.0 towards economic competitiveness, societal well-being, and environmental sustainability. Contributions will be made in providing strategic insights for researchers, professionals, and policymakers about how to use Generative AI as a trigger for sustainable digital transformation.

Keywords: *Generative Artificial Intelligence, Industry 5.0, Sustainable Technology Transformation, Human-Centric Innovation, Digital Transformation, Circular Economy, Responsible AI, Sustainability*

1. Introduction

It is the age of high-end technology and hyper-competition. Generative Artificial Intelligence (GenAI) has become one of the most revolutionary and disruptive technologies in the next wave of industrial revolution. In contrast to traditional artificial intelligence that executes activities such as prediction, classification, and automation, GenAI has the ability to create new knowledge, design options, engineering designs, software codes, textual content, and decision support through advanced foundation and large language models.

Such abilities greatly boost creativity and innovation in organizations and make decision-making easier. Companies in the manufacturing and service industry are now utilizing GenAI to build intelligent designs of products, optimize the manufacturing process, interact with customers, and innovate digitally. This ensures that companies move from automated processes to a collaborative effort of man and machine, thus forming the base of sustainability in Industry 5.0 (Kamalabai et al., 2025). The Industry 5.0 marks a complete evolution of the Industry 4.0 since it focuses on human-centricity, sustainability, and resilience of an organization along with the advancements in technology. Instead of displacing the human workforce, Industry 5.0 advocates for collaboration between intelligent technologies and human skills to bring about social, environmental, and economic value. The concept of sustainable technology transformation in this context entails embedding digital technologies along with production responsibilities, principles of circular economy, optimization of resources, and innovation with environmental consciousness (Bhanot & Gaikwad, 2025). GenAI facilitates sustainable technology transformation by providing intelligent simulation, digital twin, predictive maintenance, adaptive manufacturing, and optimization of industrial resources. This allows companies to save waste, energy consumption, manage lifecycles effectively, and be more efficient and environmentally friendly at the same time. Thus, GenAI is an important technological driver of sustainable industrial ecosystems (Amirkhizi et al., 2025).

The growing integration of Generative AI into industrial ecosystems has also transformed organizational decision-making and technology management. Modern enterprises increasingly combine GenAI with Industrial Internet of Things (IIoT), cloud computing, robotics, cyber-physical systems, blockchain, and advanced analytics to create intelligent, adaptive, and resilient production environments. Such technological convergence enhances organizational agility, strengthens supply chain resilience, facilitates predictive risk management, and enables continuous innovation in response to dynamic market conditions. The widespread implementation of GenAI also introduces significant challenges relating to ethical governance, cybersecurity, algorithmic transparency, workforce reskilling, intellectual property protection, and regulatory compliance. Addressing these multidimensional issues requires organizations to adopt responsible AI governance frameworks that balance technological innovation with human values, sustainability objectives, and long-term societal welfare, thereby ensuring trustworthy industrial transformation (Ali et al., 2025). Against this backdrop, the present study explores the strategic role of Generative Artificial Intelligence in accelerating sustainable technology transformation beyond traditional automation within the Industry 5.0 framework. The paper argues that future industrial competitiveness will increasingly depend upon the effective integration of GenAI with sustainability-oriented business strategies that simultaneously improve productivity, environmental stewardship, organizational resilience, innovation capability, and employee empowerment. By synthesizing contemporary theoretical perspectives and emerging industrial practices, the study develops a comprehensive understanding of how GenAI contributes to sustainable digital transformation while identifying critical implementation opportunities and governance challenges. The findings are expected to provide valuable insights for researchers, policymakers, technology developers, and industry leaders seeking to leverage Generative AI as a catalyst for sustainable industrial development and responsible technological advancement in the evolving global economy (Breque et al., 2021).

2. Background of Study

The rapid evolution of industrial systems has shifted organizational priorities from automation-driven productivity to intelligent, sustainable, and human-centric value creation. While earlier industrial revolutions primarily focused on mechanization, electrification, and digital automation, the contemporary industrial landscape demands technologies that simultaneously improve economic performance,

environmental sustainability, and workforce well-being. Industry 5.0 has therefore emerged as a strategic paradigm that complements technological excellence with resilience, inclusiveness, and responsible innovation. Within this context, organizations are increasingly adopting advanced digital technologies that support collaborative intelligence rather than complete automation. This transformation reflects a growing recognition that sustainable industrial development depends on balancing technological progress with human creativity, ethical governance, and long-term societal value. The Industry 5.0 has become a guiding framework for enterprises seeking sustainable competitive advantage through intelligent technological transformation (Hosseinian Far et al., 2025).

Generative Artificial Intelligence represents a significant advancement in digital intelligence because of its ability to generate original content, optimize engineering solutions, create digital prototypes, automate knowledge-intensive tasks, and support complex decision-making (Gaikwad, 2024). Unlike conventional AI applications that primarily analyze historical datasets, Generative AI enables organizations to simulate future scenarios, develop innovative product designs, improve industrial documentation, and accelerate research and development activities. These capabilities are particularly valuable for manufacturing industries that require continuous innovation, rapid customization, and adaptive production systems. As industries become increasingly data-driven, Generative AI serves as a strategic technology that enhances operational flexibility while supporting intelligent collaboration between humans and machines across multiple industrial processes (Waqas & Naseem, 2025). However, the imbalance may lead to digital stress at times creating long-lasting impact (Gaikwad & Bhattacharya, 2024).

Sustainable technology transformation has become an essential strategic objective for governments and industries in response to climate change, resource scarcity, and increasing environmental regulations. Modern organizations are expected to reduce carbon emissions, improve energy efficiency, optimize resource utilization, and implement circular economy practices without compromising productivity or profitability. Generative Artificial Intelligence contributes to these objectives by facilitating intelligent energy management, predictive maintenance, digital twin simulations, sustainable product lifecycle design, and optimized supply chain operations. These capabilities enable organizations to reduce material waste, improve resource efficiency, and support evidence-based sustainability decision-making, thereby strengthening the integration of digital transformation with environmental stewardship and resilient industrial development. Despite the transformative potential of Generative Artificial Intelligence, its successful implementation requires organizations to address several technological, organizational, and ethical challenges. The adoption of GenAI introduces concerns regarding algorithmic transparency; explainability, cybersecurity, workforce readiness, intellectual property protection, regulatory compliance, and responsible governance. The organizations must ensure that AI-driven innovation remains aligned with human values and sustainability objectives rather than focusing exclusively on efficiency gains. Developing trustworthy AI ecosystems therefore requires integrated governance frameworks that combine technological innovation with ethical principles, organizational resilience, and stakeholder collaboration. Addressing these multidimensional challenges will be fundamental for realizing the full potential of Industry 5.0 and achieving sustainable industrial transformation in the coming decade.

3. Rationale of Study

The rapid advancement of Generative Artificial Intelligence (GenAI) has transformed industrial innovation by extending the capabilities of traditional automation toward intelligent content generation, adaptive decision-making and human-AI collaboration. Despite the growing adoption of GenAI across manufacturing, engineering, logistics, and service industries, existing research has predominantly focused

on technical performance, automation efficiency, and productivity enhancement. Comparatively limited attention has been given to understanding how GenAI contributes to sustainable technology transformation within the broader Industry 5.0 paradigm, where human-centricity, environmental sustainability, and industrial resilience are equally important. This imbalance in the literature highlights the need for conceptual research that examines GenAI not merely as an automation tool but as a strategic enabler of sustainable industrial ecosystems capable of generating long-term economic, environmental, and social value (Xu et al., 2025).

The transition toward Industry 5.0 requires organizations to integrate intelligent technologies with sustainability-oriented business strategies while addressing emerging challenges such as ethical AI governance, workforce transformation, circular economy implementation, and responsible innovation. However, industries continue to face uncertainty regarding the effective deployment of GenAI for achieving sustainability objectives without compromising transparency, security, regulatory compliance, or human well-being. Furthermore, fragmented research across artificial intelligence, sustainability, and industrial transformation has limited the development of an integrated conceptual perspective that connects these interdisciplinary domains. Therefore, this study seeks to bridge this knowledge gap by synthesizing contemporary theoretical insights and industrial practices to explain the strategic role of Generative Artificial Intelligence in accelerating sustainable technology transformation beyond automation. The findings are expected to support researchers, policymakers, and industry practitioners in designing responsible AI-driven strategies aligned with the vision of Industry 5.0 and global sustainable development priorities (Rane, 2025).

4. Objectives of Study

- To examine the role of Generative Artificial Intelligence in accelerating sustainable technology transformation within the Industry 5.0 ecosystem
- To analyze the contribution of Generative Artificial Intelligence toward enhancing human-centric innovation, operational efficiency, and environmental sustainability across industrial sectors
- To identify the key technological, organizational, and ethical challenges influencing the adoption of Generative Artificial Intelligence for sustainable industrial transformation
- To explore the integration of Generative Artificial Intelligence with Industry 5.0 technologies in promoting resilient, intelligent, and sustainable manufacturing systems
- To propose a conceptual framework illustrating the strategic relationship between Generative Artificial Intelligence, sustainable technology transformation, and Industry 5.0 for future research and managerial applications

5. Review of Literature

Recent research has established that Generative Artificial Intelligence (GenAI) is redefining the evolution of Industry 5.0 by shifting industrial priorities from automation-centric production toward intelligent, human-centric, and sustainable manufacturing. The study highlighted that GenAI enhances operational excellence through intelligent process optimization, adaptive decision-making, collaborative human-AI systems, and continuous organizational learning. Unlike Industry 4.0, where efficiency remained the primary objective, Industry 5.0 leverages GenAI to simultaneously improve productivity, workforce empowerment, resilience, and sustainability. The authors further emphasized that organizations integrating GenAI into strategic operations demonstrate greater innovation capability, resource optimization, and long-term competitiveness, making Generative AI a foundational technology for future industrial ecosystems (Khan et al., 2026).

Ghobakhloo et al. (2024) investigated the practical applications of Generative Artificial Intelligence in manufacturing and reported that GenAI substantially contributes to responsible manufacturing by enabling intelligent product design, engineering simulations, predictive maintenance, digital twins, and sustainable production planning. The study proposed a strategic roadmap demonstrating how manufacturers can prioritize GenAI implementation to achieve Industry 5.0 sustainability objectives. It further observed that GenAI enhances resource efficiency, supports circular manufacturing, improves environmental performance, and strengthens organizational resilience by integrating intelligent knowledge generation with human expertise. The research concluded that successful adoption requires aligning technological innovation with sustainability goals and organizational capabilities. The examined the contribution of Generative Artificial Intelligence toward achieving Industry 5.0 sustainability goals and found that AI-powered systems significantly improve real-time decision-making, intelligent risk identification, energy optimization, and resource management across industrial operations (Choudhury et al, 2024).

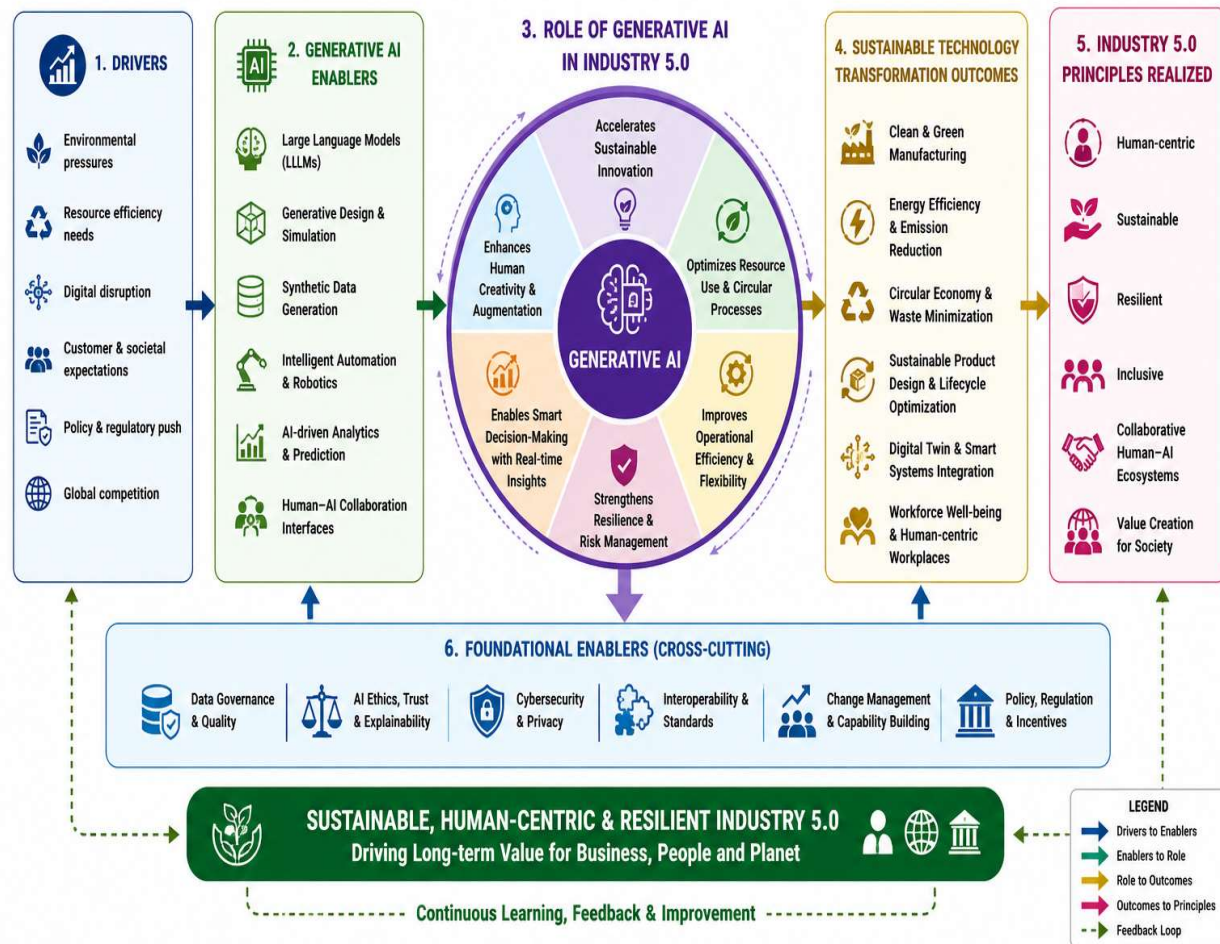
Waqas and Naseem (2025) conducted a comparative assessment of Industry 4.0 and Industry 5.0 and concluded that Artificial Intelligence plays a pivotal role in transforming conventional digital manufacturing into sustainable and human-centric industrial systems. Their findings revealed that AI-driven Industry 5.0 environments achieved superior resource utilization, reduced carbon emissions, and strengthened adaptive manufacturing capabilities compared with Industry 4.0 practices. The study also identified ethical governance, workforce development, cybersecurity, and algorithmic transparency as major determinants influencing successful AI adoption. The authors recommended integrating responsible AI frameworks with sustainability-oriented industrial strategies to maximize long-term organizational and environmental performance. Through a comprehensive systematic literature review, identified Industry 5.0 as an emerging multidisciplinary research domain centered on human-centricity, resilience, sustainability, and trustworthy Artificial Intelligence. The review revealed that future industrial competitiveness will increasingly depend on integrating advanced AI technologies with ethical governance, collaborative intelligence, digital transformation, and sustainable innovation practices. The authors also highlighted significant research gaps relating to Generative AI implementation, interdisciplinary governance, workforce reskilling, explainable AI, and sustainability performance measurement.

6. Discussion and Analysis

Generative Artificial Intelligence is transforming Industry 5.0 by shifting industrial development beyond conventional automation toward intelligent, human-centric, and sustainability-driven innovation. Unlike traditional AI systems that primarily execute predefined tasks, GenAI enables industries to generate engineering designs, optimize production processes, create digital prototypes, and support strategic decision-making through continuous learning. This transition strengthens collaboration between human expertise and intelligent systems, allowing organizations to improve productivity while simultaneously addressing environmental and social objectives.

Figure 1: A Conceptual Framework on Gen AI in Sustainability Technology Transformation in Industry 5.0

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The proposed conceptual framework illustrates how Generative Artificial Intelligence (GenAI) functions as the central catalyst in accelerating sustainable technology transformation within the Industry 5.0 paradigm. The framework begins with key drivers such as environmental concerns, resource efficiency requirements, rapid digital disruption, changing customer expectations, regulatory pressures, and global competition, which collectively compel industries to embrace intelligent transformation. These drivers stimulate the adoption of Generative AI enablers, including large language models (LLMs), generative design, synthetic data generation, intelligent automation, AI-driven analytics, and human-AI collaboration platforms. Positioned at the core of the framework, Generative AI enhances creativity, supports data-driven decision-making, optimizes resource utilization, strengthens organizational resilience, improves operational flexibility, and accelerates sustainable innovation. Thus, GenAI serves not merely as a technological tool but as a strategic capability that integrates human intelligence with advanced computational systems to create adaptive, efficient, and sustainable industrial ecosystems.

The framework further demonstrates that the effective application of Generative AI produces significant sustainable technology transformation outcomes, including clean and green manufacturing, improved energy efficiency, circular economy practices, sustainable product lifecycle optimization, digital twin integration, and enhanced employee well-being. These outcomes collectively contribute to realizing the core principles of Industry 5.0, namely human-centricity, sustainability, resilience, inclusiveness, collaborative human-AI ecosystems, and long-term societal value creation. The model also emphasizes the

importance of cross-cutting foundational enablers—such as robust data governance, trustworthy AI, cybersecurity, interoperability standards, organizational change management, workforce capability development, and supportive public policies—which ensure the responsible and ethical deployment of AI technologies. Finally, the continuous feedback loop signifies that learning, innovation, and technological refinement are ongoing processes, enabling organizations to continuously improve their sustainability performance and maintain competitive advantage while creating balanced value for business, society, and the environment.

GenAI serves as a catalyst for sustainable technology transformation by integrating innovation, resilience, and responsible industrial practices into modern production ecosystems. These developments indicate that future industrial competitiveness will depend not only on technological sophistication but also on the ability to create sustainable value through collaborative intelligence (Hosseinian Far et al., 2025). Generative AI significantly enhances resource optimization by improving energy efficiency, reducing material waste, enabling predictive maintenance, and supporting intelligent lifecycle management. AI-driven digital twins and simulation models allow industries to evaluate multiple production scenarios before implementation, thereby minimizing operational risks and environmental impacts. Furthermore, intelligent optimization contributes to circular manufacturing by extending product life cycles, improving remanufacturing processes, and reducing unnecessary resource consumption. GenAI should be viewed as an enabling technology that simultaneously advances environmental stewardship and operational excellence within Industry 5.0 ecosystems (Jourabchi Amirkhizi et al., 2025).

The widespread adoption of Generative AI also creates substantial organizational opportunities by enhancing innovation capability, workforce productivity, and strategic agility. Intelligent knowledge generation enables faster research and development, supports customized manufacturing, improves supply chain responsiveness, and facilitates data-driven managerial decision-making. However, successful implementation requires organizations to develop strong digital capabilities, AI governance mechanisms, and employee competencies. Human capital development, continuous reskilling, interdisciplinary collaboration, and organizational readiness become critical success factors in realizing the full benefits of GenAI. The organizations should adopt a balanced transformation strategy where technological advancement is complemented by workforce empowerment and responsible innovation practices to maximize sustainable industrial performance (Khan et al., 2026). Concerns regarding algorithmic transparency, data privacy, cybersecurity, intellectual property protection, bias, explain ability, and regulatory compliance continue to influence organizational adoption decisions. Excessive dependence on autonomous AI systems may also reduce human oversight and create new operational risks if appropriate governance frameworks are absent. Therefore, the future success of Industry 5.0 depends upon establishing trustworthy AI ecosystems that combine technological innovation with ethical governance, sustainability principles, and stakeholder accountability. A balanced integration of Generative AI with human judgment and responsible policy frameworks will enable organizations to achieve sustainable technology transformation while maintaining resilience, inclusiveness, and long-term societal value (Vyhmeister & Castañe, 2024).

7. Findings of Study

- The study finds that Generative Artificial Intelligence has evolved beyond conventional automation and has become a strategic driver of sustainable technology transformation within the Industry 5.0 ecosystem. Unlike traditional AI applications that primarily automate repetitive tasks, GenAI facilitates intelligent content generation, engineering design, predictive analytics, digital simulation, and knowledge creation, thereby strengthening organizational innovation, operational

agility, and collaborative decision-making. This transition signifies a shift from machine-centric productivity toward human–AI collaboration, where technology complements human creativity and expertise to generate sustainable industrial value.

- The analysis further reveals that GenAI significantly contributes to environmental sustainability by optimizing resource utilization, reducing energy consumption, minimizing production waste, and supporting circular economy initiatives. Through intelligent digital twins, predictive maintenance, adaptive manufacturing, and lifecycle optimization, organizations can improve production efficiency while lowering their environmental footprint. These capabilities demonstrate that sustainable technology transformation is no longer limited to digitalization but increasingly depends on AI-enabled intelligent systems that integrate economic growth with environmental responsibility and social well-being.
- Another important finding indicates that the successful implementation of Generative AI depends on organizational readiness, workforce competencies, ethical governance, and digital infrastructure rather than technology adoption alone. Industries that invest in employee reskilling, interdisciplinary collaboration, responsible AI governance, cybersecurity, and data quality are better positioned to realize the full benefits of Industry 5.0. Consequently, sustainable industrial transformation requires balanced investments in technological capabilities as well as human capital development, organizational culture, and strategic leadership.
- The study concludes that Generative Artificial Intelligence serves as a foundational enabler of Industry 5.0 by simultaneously enhancing innovation capability, industrial resilience, sustainability performance, and long-term competitiveness. However, realizing these benefits requires comprehensive governance frameworks that address explainability, transparency, intellectual property protection, regulatory compliance, and stakeholder accountability. The proposed conceptual perspective therefore highlights that the future of sustainable industrial ecosystems will depend on the responsible integration of Generative AI with human-centric innovation, ethical decision-making and sustainability-oriented business strategies.

8. Conclusion

The transition from Industry 4.0 to Industry 5.0 signifies a fundamental shift from automation-centric industrial systems to human-centric, sustainable, and resilient technological ecosystems. This study demonstrates that Generative Artificial Intelligence is not merely an advanced automation tool but a strategic enabler of sustainable technology transformation capable of enhancing innovation, intelligent decision-making, resource optimization, and collaborative human–AI interactions. By integrating capabilities such as generative design, predictive analytics, digital twins, and intelligent knowledge generation, GenAI enables organizations to achieve greater operational efficiency while simultaneously supporting environmental sustainability, circular economy practices, and long-term industrial resilience. The convergence of Generative AI and Industry 5.0 creates new opportunities for organizations to balance technological advancement with human creativity, ethical governance, and sustainable value creation. The study further concludes that the successful realization of Industry 5.0 depends on the responsible adoption of Generative Artificial Intelligence supported by robust governance frameworks, workforce reskilling, digital infrastructure, cybersecurity, and regulatory compliance. Sustainable industrial transformation requires organizations to move beyond productivity-focused automation toward intelligent ecosystems that integrate economic competitiveness with environmental stewardship and social well-being. The proposed conceptual perspective provides a comprehensive foundation for future empirical investigations while offering practical insights for policymakers, industry leaders, and technology developers seeking to harness the transformative potential of Generative AI. As industries continue to evolve, responsible and

human-centric implementation of Generative Artificial Intelligence will remain a critical determinant of sustainable technological progress and global industrial competitiveness.

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