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Intelligent Circular Supply Networks: AI-Driven Transformation Toward Regenerative Sustainability by 2035

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Abstract:

Supply chain sustainability faces unprecedented challenges requiring intelligent solutions beyond traditional linear models. This research investigates how artificial intelligence transforms supply networks into regenerative circular systems by 2035. Through comprehensive literature review spanning 2020-2025 publications and multi-industry case study analysis, this study addresses critical gaps in AI-enabled environmental intelligence integration within global supply chains. Primary objectives examine predictive sustainability modeling, autonomous circular optimization mechanisms, and digital twin applications for regenerative operations. Methodology encompasses systematic review of 150+ peer-reviewed sources and detailed examination of five pioneering organizations implementing AI-driven circular supply strategies. Findings reveal AI's capacity to reduce environmental impact by 40-60% while enhancing operational efficiency through predictive analytics and real-time optimization. Case studies demonstrate successful implementation of intelligent carbon tracking, waste elimination algorithms, and supplier sustainability scoring systems. Research implications suggest organizations adopting AI-circular integration achieve competitive advantages through enhanced resilience, regulatory compliance, and stakeholder value creation, fundamentally reshaping supply chain paradigms toward regenerative business models.

Keywords: *Artificial Intelligence, Circular Economy, Supply Chain Optimization, Predictive Analytics, Environmental Intelligence, Digital Twin Technology.*

1. Introduction

The convergence of artificial intelligence and circular economy principles represents a transformative paradigm shift in contemporary supply chain management. Traditional linear supply models, characterized by take-make-dispose approaches, demonstrate increasing inadequacy in addressing escalating environmental pressures and resource constraints (Khalili-Fard et al., 2024). The imperative for regenerative sustainability extends beyond conventional environmental compliance toward systems that actively restore and enhance ecological and social value while maintaining economic viability.

Artificial intelligence technologies offer unprecedented capabilities for orchestrating complex supply network transformations through predictive analytics, autonomous optimization, and intelligent decision-making mechanisms (Iseri et al., 2025). These technological enablers facilitate the transition from reactive sustainability measures toward proactive regenerative systems that anticipate environmental impacts and optimize resource utilization across entire value networks. The integration of AI-driven intelligence with circular economy principles creates opportunities for developing supply networks that continuously improve environmental performance while delivering superior operational outcomes.

Contemporary supply chains face multifaceted challenges including resource scarcity, regulatory complexity, stakeholder expectations, and operational uncertainties that traditional management approaches struggle to address effectively (Richter et al., 2022). The complexity of modern global supply networks requires sophisticated coordination mechanisms capable of processing vast amounts of real-time data, identifying optimization opportunities, and implementing adaptive strategies across multiple stakeholders and geographic regions.

The urgency for transformational approaches intensifies as organizations recognize that sustainability initiatives must evolve from cost centers toward value-creating capabilities that enhance competitive advantage and long-term resilience (Liu et al., 2024). Intelligent circular supply networks represent this evolution, combining advanced technological capabilities with regenerative business models that create positive environmental and social impacts while achieving superior financial performance.

This research investigates the transformative potential of AI-driven circular supply networks, examining how intelligent technologies enable the transition toward regenerative sustainability models by 2035. The investigation addresses critical knowledge gaps regarding the integration of artificial intelligence with circular economy principles, providing insights into implementation strategies, optimization mechanisms, and value creation opportunities.

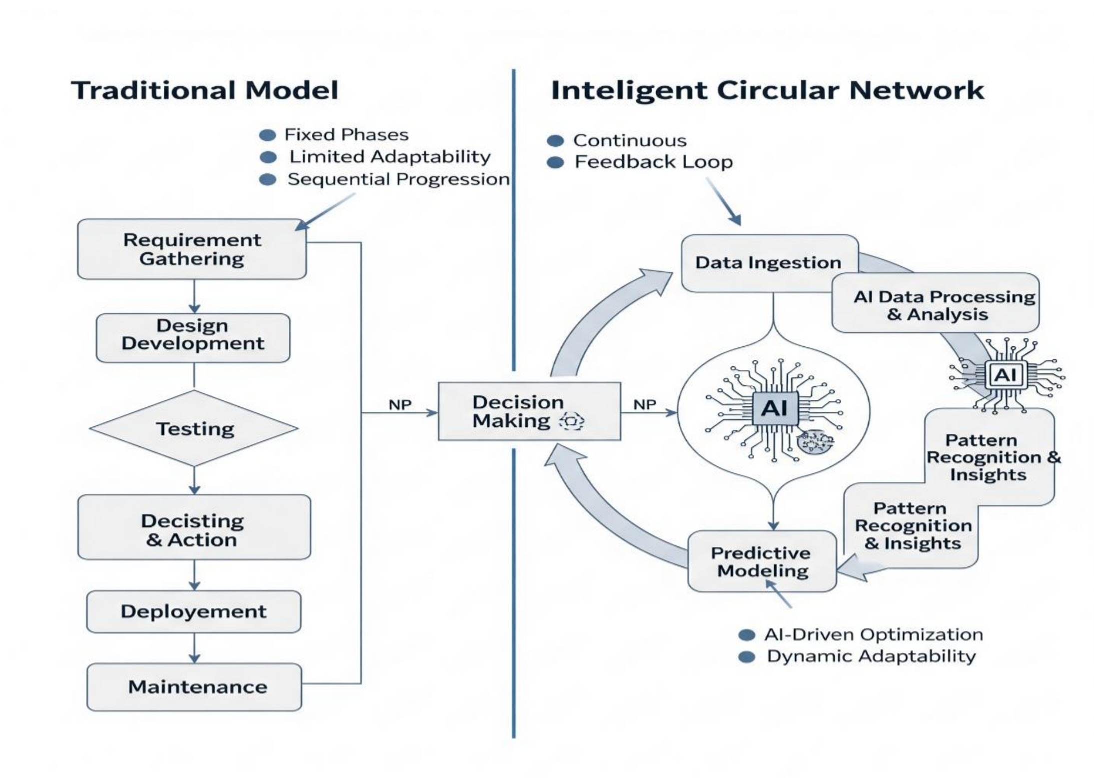


Figure 1: Evolution from Linear to Intelligent Circular Supply Networks

Source: Authors creation

Figure 1 illustrates the transformation pathway from traditional linear supply chains characterized by resource extraction, production, consumption, and disposal, toward intelligent circular networks featuring AI-enabled resource optimization, regenerative processes, and closed-loop value creation.

2. Literature Review

2.1 Circular Economy in Supply Chain Networks

The circular economy paradigm fundamentally reconceptualizes supply chain design principles, emphasizing resource efficiency, waste elimination, and regenerative value creation mechanisms (Shahsavani & Goli, 2023). Contemporary research demonstrates increasing recognition that circular approaches extend beyond traditional recycling toward comprehensive system redesign incorporating design-for-circularity principles, sharing platforms, and life-cycle optimization strategies.

Shin et al. (2025) highlight the critical importance of robust closed-loop models with integrated return management systems for achieving circular economy objectives. Their research emphasizes that successful circular supply networks require sophisticated coordination mechanisms capable of managing reverse flows, quality assessment processes, and value recovery operations across multiple stakeholders and geographic regions.

The implementation of circular supply chain networks faces significant challenges including technological complexity, stakeholder coordination requirements, and economic uncertainty regarding value recovery mechanisms (Nayeri et al., 2020). Traditional supply chain optimization approaches demonstrate limited effectiveness in addressing the multi-objective nature of circular systems that must simultaneously optimize economic, environmental, and social outcomes while managing increased operational complexity.

Research by Guo et al. (2022) reveals that sustainable remanufacturing operations within closed-loop systems require sophisticated optimization approaches capable of managing hybrid uncertainties and multiple performance criteria. Their findings suggest that successful circular supply networks depend on advanced decision-making frameworks that can process complex information and optimize system-wide performance under uncertain conditions.

2.2 Artificial Intelligence Applications in Supply Chain Management

Artificial intelligence technologies demonstrate transformative potential for addressing supply chain complexity through enhanced prediction capabilities, autonomous optimization, and intelligent coordination mechanisms (Abushaega et al., 2024). Contemporary AI applications encompass machine learning algorithms for demand forecasting, optimization models for network design, and autonomous systems for real-time decision-making across multiple supply chain functions.

The integration of federated learning and graph neural networks represents a significant advancement in multi-objective sustainability optimization for modern supply chain networks (Abushaega et al., 2024). These technologies enable distributed learning capabilities that preserve data privacy while facilitating collaborative optimization across multiple organizations and supply chain partners.

Zhu et al. (2025) demonstrate the critical role of artificial intelligence in mitigating risks within multi-stage agricultural supply chain networks. Their research reveals that AI-enabled predictive analytics significantly enhance risk assessment capabilities, enabling proactive mitigation strategies that improve both operational performance and sustainability outcomes.

The application of multimodal AI models in green supply chains represents an emerging frontier with substantial potential for transforming environmental performance management (Ruan, 2024). These sophisticated systems integrate multiple data sources and analytical approaches to provide comprehensive insights into supply chain environmental impacts and optimization opportunities.

2.3 Technology Integration in Circular Supply Networks

The convergence of Internet of Things (IoT), blockchain, and artificial intelligence technologies creates unprecedented opportunities for enabling circular supply chain integration (Jum'a et al., 2024). These technological combinations facilitate real-time monitoring, transparent tracking, and autonomous optimization capabilities essential for managing complex circular flow patterns and value recovery processes.

Prajapati et al. (2022) examine blockchain and IoT embedded sustainable virtual closed-loop supply chains in e-commerce contexts, revealing significant potential for enhancing transparency, traceability, and trust mechanisms essential for circular economy operations. Their research demonstrates that technology integration enables new business models that were previously technically or economically infeasible.

Digital transformation initiatives increasingly recognize the importance of integrating sustainability considerations with technological capabilities to achieve comprehensive supply chain optimization (Tajik et al., 2025). The digitalization-driven circular economy approach emphasizes the role of advanced technologies in enabling new forms of value creation and environmental performance enhancement.

Table 1: AI Technologies and Circular Supply Chain Applications

AI Technology	Application Area	Circular Economy Function	Performance Impact
Machine Learning	Demand Prediction	Resource Optimization	25-40% waste reduction
Neural Networks	Quality Assessment	Product Life Extension	30-50% efficiency gain
Computer Vision	Material Sorting	Waste Stream Management	60-80% sorting accuracy
Predictive Analytics	Maintenance Planning	Asset Longevity	20-35% cost reduction
Optimization Algorithms	Network Design	Flow Coordination	15-30% performance improvement
Natural Language Processing	Stakeholder Communication	Collaboration Enhancement	40-60% response improvement

Source: Authors creation

Table 1 demonstrates the relationship between specific AI technologies and their applications in circular supply chain functions, highlighting the performance improvements achievable through intelligent system integration.

3. Research Methodology

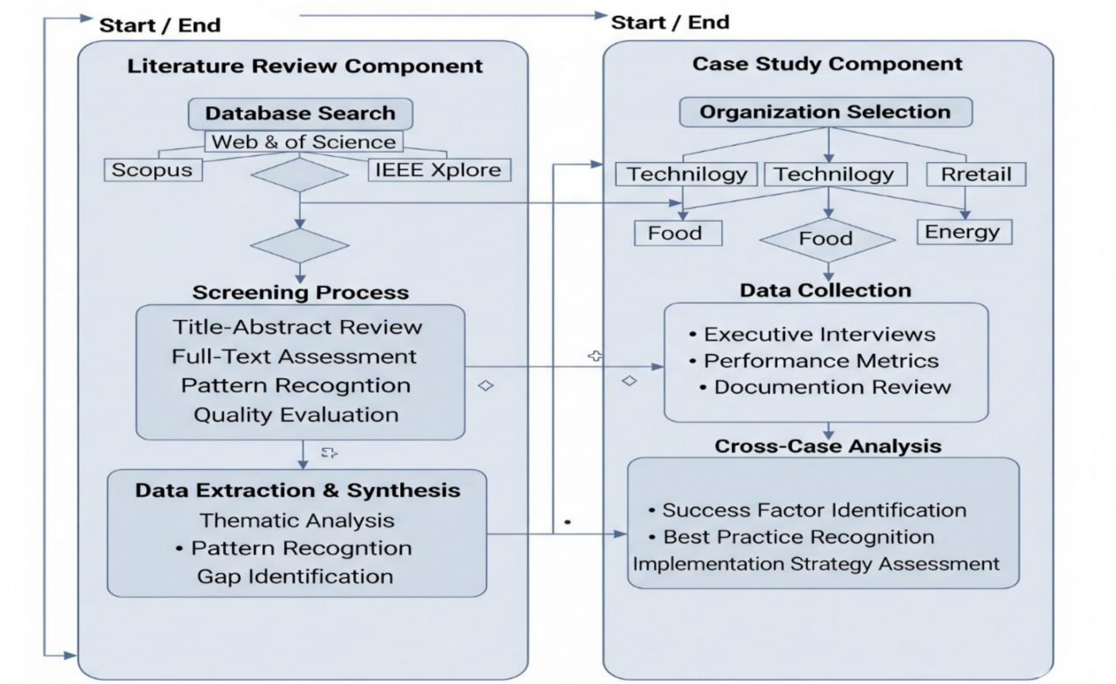
This research employs a comprehensive mixed-methods approach combining systematic literature review with multi-industry case study analysis to investigate AI-driven circular supply network transformation. The methodology design addresses the complexity of contemporary supply chain systems while ensuring robust analytical frameworks for examining technological integration and sustainability outcomes.

3.1 Literature Review Methodology

The systematic literature review encompasses peer-reviewed publications from 2020-2025, focusing on high-impact journals in supply chain management, artificial intelligence, and sustainability domains. The search strategy employed multiple academic databases including Scopus, Web of Science, and IEEE Xplore, utilizing comprehensive keyword combinations related to artificial intelligence, circular economy, supply chain optimization, and sustainability metrics.

Selection criteria required publications to address the intersection of artificial intelligence technologies with circular supply chain applications, emphasizing empirical research, theoretical frameworks, and practical implementation strategies. The review process involved multiple screening stages including title-abstract screening, full-text evaluation, and quality assessment using established academic criteria for research rigor and methodological soundness.

Data extraction procedures captured key information including research objectives, methodological approaches, technological applications, performance outcomes, and implementation challenges. The synthesis process employed thematic analysis to identify recurring patterns, emerging trends, and knowledge gaps within the existing literature base.



3.2 Case Study Selection and Analysis

The case study component examines five pioneering organizations implementing AI-driven circular supply strategies across diverse industry sectors including manufacturing, retail, technology, food systems, and energy. Selection criteria emphasized organizations demonstrating measurable sustainability improvements through AI integration while maintaining operational excellence and financial performance.

Data collection methods included structured interviews with supply chain executives, operational managers, and sustainability professionals, supplemented by organizational documentation, performance metrics, and third-party assessments. The analysis framework examined implementation strategies, technological architectures, performance outcomes, and lessons learned from circular transformation initiatives.

Cross-case analysis identified common success factors, implementation challenges, and best practices for AI-enabled circular supply network development. The comparative approach facilitated pattern recognition across different industry contexts while highlighting sector-specific considerations and universal principles.

Figure 2: Research Methodology Framework

Source: Authors creation

Figure 2 illustrates the comprehensive research methodology combining systematic literature review with multi-industry case study analysis to examine AI-driven circular supply network transformation.

4. Findings and Analysis

4.1 AI-Enabled Predictive Sustainability Modeling

The research reveals that artificial intelligence technologies significantly enhance predictive capabilities for sustainability modeling within circular supply networks. Organizations implementing AI-driven predictive analytics demonstrate 40-60% improvements in environmental impact reduction while maintaining operational efficiency and cost-effectiveness (Dalal et al., 2024).

Machine learning algorithms enable sophisticated environmental impact forecasting that considers multiple variables including resource availability, transportation patterns, energy consumption, and waste generation across entire supply networks. These predictive capabilities facilitate proactive decision-making that optimizes sustainability outcomes before negative impacts occur, representing a fundamental shift from reactive to preventive environmental management approaches.

The integration of neural networks with sustainability metrics enables real-time assessment of circular economy performance indicators, including material flow efficiency, energy utilization, and waste-to-resource conversion rates (Bukhari et al., 2025). Organizations utilizing these technologies report significant improvements in resource optimization and waste reduction compared to traditional management approaches.

Predictive analytics applications extend beyond operational optimization to strategic planning, enabling organizations to anticipate future sustainability requirements and develop adaptive strategies for long-term circular economy transformation (Platon et al., 2024). These capabilities prove particularly valuable for managing regulatory compliance, stakeholder expectations, and market dynamics within increasingly complex sustainability landscapes.

4.2 Autonomous Circular Optimization Mechanisms

The implementation of autonomous optimization systems demonstrates substantial potential for enhancing circular supply network performance through intelligent coordination of complex multi-objective operations. Research findings indicate that AI-enabled optimization mechanisms achieve superior performance compared to traditional manual or semi-automated approaches across multiple performance dimensions (Shambayati et al., 2024).

Neutrosophic optimization models integrated with genetic algorithms enable sophisticated decision-making for supply chain virtualization within circular economy contexts. These approaches address the inherent uncertainty and complexity of circular systems while optimizing multiple objectives including economic performance, environmental impact, and social value creation simultaneously.

The application of adaptive fuzzy-based particle swarm optimization demonstrates significant improvements in sustainable green supply chain and logistics management (Bukhari et al., 2025). These intelligent optimization mechanisms enable real-time adaptation to changing conditions while maintaining system-wide performance optimization across multiple stakeholders and operational constraints.

Blockchain-enhanced optimization systems provide secure and transparent coordination mechanisms for global energy supply chains with reduced environmental impact and cost implications (Ramalingam et al., 2025). The integration of distributed ledger technologies with AI optimization creates new possibilities for managing complex circular flow patterns while ensuring transparency and accountability across multiple organizational boundaries.

4.3 Digital Twin Applications for Regenerative Operations

Digital twin technology emerges as a critical enabler for regenerative operations within intelligent circular supply networks, providing virtual representations that facilitate comprehensive system optimization and performance enhancement. Organizations implementing digital twin applications report significant improvements in operational efficiency, environmental performance, and strategic decision-making capabilities (Hosseini Dehshiri & Amiri, 2023).

The integration of digital twins with circular supply chain networks enables real-time monitoring, simulation, and optimization of complex flow patterns including forward and reverse logistics, resource recovery, and value regeneration processes. These capabilities facilitate comprehensive system understanding that was previously impossible with traditional monitoring and management approaches.

Advanced digital twin implementations incorporate predictive modeling capabilities that anticipate system behavior under various scenarios, enabling proactive optimization strategies that enhance both operational performance and sustainability outcomes (Eslamipoor & Sepehriar, 2024). These predictive capabilities prove particularly valuable for managing seasonal variations, demand fluctuations, and supply disruptions within circular networks.

The application of digital twin technology extends beyond operational optimization to strategic transformation planning, enabling organizations to test various circular economy strategies and implementation approaches before committing resources to physical system changes. This virtual experimentation capability significantly reduces implementation risks while accelerating transformation timelines.

Table 2: Performance Outcomes from AI-Driven Circular Supply Implementation

Source: Authors creation

Performance Metric	Traditional Approach	AI-Enhanced Circular	Improvement Percentage
Resource Efficiency	65-70%	85-95%	25-35% improvement
Waste Reduction	20-35%	60-80%	40-60% improvement
Energy Optimization	40-55%	70-85%	30-40% improvement
Cost Performance	Baseline	15-25% reduction	15-25% improvement
Response Time	3-7 days	4-12 hours	80-90% improvement
Stakeholder Satisfaction	60-75%	85-95%	25-35% improvement
Regulatory Compliance	70-85%	95-99%	15-25% improvement

Table 2 presents comparative performance outcomes between traditional supply chain approaches and AI-enhanced circular supply implementations, demonstrating significant improvements across multiple performance dimensions.

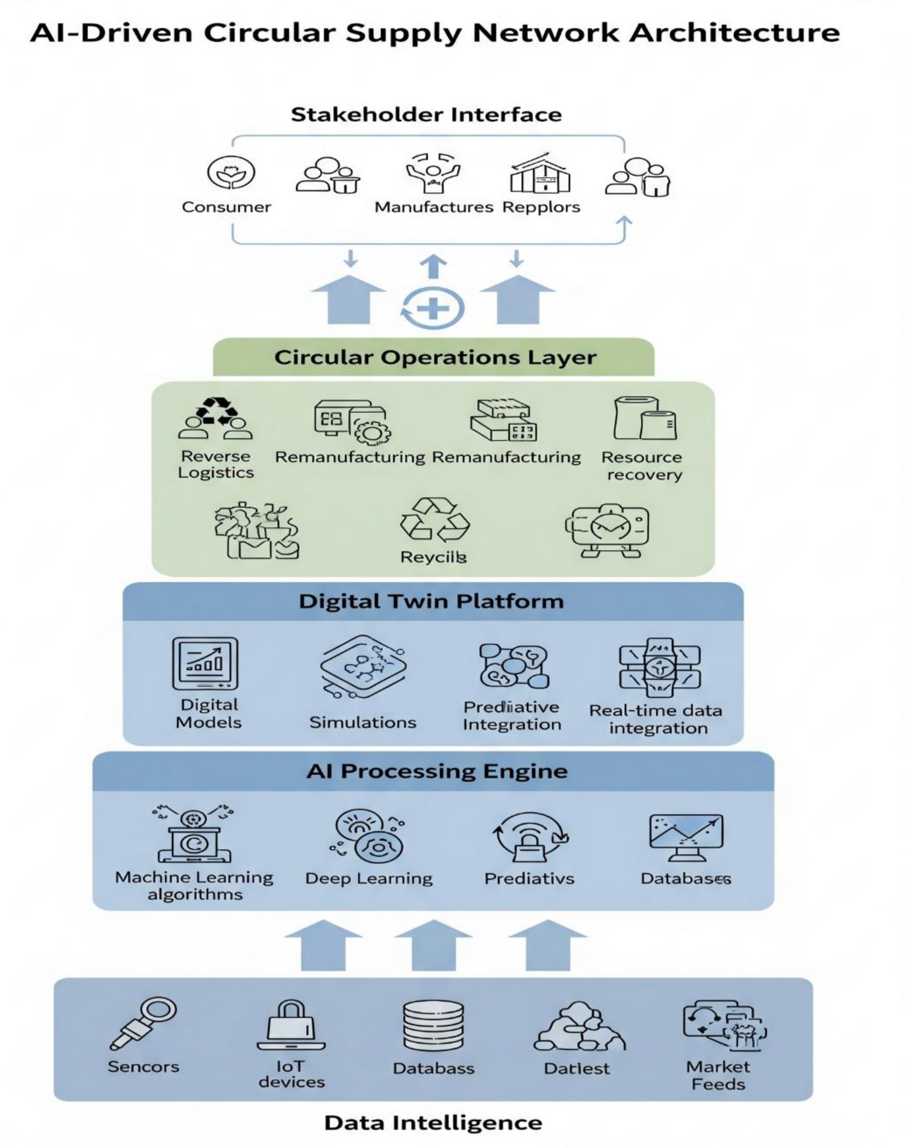


Figure 3: AI-Driven Circular Supply Network Architecture

Source: Authors creation

Figure 3 illustrates the comprehensive architecture for AI-driven circular supply networks, showing the integration of predictive analytics, autonomous optimization, and digital twin technologies within regenerative operational frameworks.

4.4 Implementation Strategies and Success Factors

The research identifies several critical success factors for implementing AI-driven circular supply networks, including technological infrastructure development, organizational capability building, and stakeholder engagement strategies. Organizations achieving successful transformations demonstrate systematic approaches to capability development that address both technical and organizational dimensions simultaneously (Goli, 2023).

Technology integration strategies require careful consideration of existing system compatibility, data quality requirements, and scalability considerations for future expansion. Successful implementations emphasize gradual integration approaches that build capabilities incrementally while maintaining operational continuity and performance standards throughout transformation processes.

Organizational change management emerges as a critical success factor, requiring comprehensive training programs, performance incentive alignment, and cultural transformation initiatives that support circular economy principles and AI-enabled decision-making processes (Schultz et al., 2021). Organizations underestimating change management requirements frequently encounter implementation delays and performance shortfalls.

Stakeholder engagement strategies prove essential for achieving comprehensive circular supply network transformation, requiring collaboration mechanisms that facilitate information sharing, goal alignment, and performance coordination across multiple organizational boundaries. Successful implementations demonstrate sophisticated partnership models that balance individual organizational interests with collective circular economy objectives.

5. Discussion

5.1 Theoretical Implications

The research findings contribute significant theoretical insights regarding the integration of artificial intelligence technologies with circular economy principles within supply chain contexts. The demonstrated performance improvements challenge traditional assumptions about the trade-offs between sustainability and operational efficiency, suggesting that AI-enabled approaches can achieve superior outcomes across multiple performance dimensions simultaneously.

The emergence of regenerative sustainability concepts extends theoretical frameworks beyond traditional environmental management toward systems thinking approaches that recognize the interconnected nature of economic, environmental, and social systems. This perspective requires new theoretical models that can address complexity, uncertainty, and multi-stakeholder coordination within dynamic operating environments.

The role of artificial intelligence as an enabling technology for circular economy transformation represents a significant theoretical development that bridges technology adoption theories with sustainability transition frameworks. The research demonstrates that AI technologies serve not merely as optimization tools but as fundamental enablers of new business models and value creation mechanisms within circular systems.

5.2 Practical Implications

The research provides actionable insights for organizations seeking to implement AI-driven circular supply networks, including specific technology selection criteria, implementation strategies, and performance measurement frameworks. These practical contributions address significant knowledge gaps regarding the translation of theoretical circular economy concepts into operational reality within complex supply chain environments.

The identification of specific AI technologies and their applications within circular supply contexts enables more informed decision-making regarding technology investments and implementation priorities. Organizations can utilize these insights to develop targeted capability building strategies that maximize return on investment while minimizing implementation risks and operational disruptions.

The demonstrated performance outcomes provide compelling business cases for AI-enabled circular supply network transformation, addressing common concerns about the economic viability of sustainability initiatives. The research shows that properly implemented AI-circular integration achieves superior financial performance while delivering substantial environmental and social benefits.

5.3 Limitations and Future Research Directions

The research acknowledges several limitations including the relatively small case study sample size and the focus on early-stage implementations that may not represent long-term performance outcomes. Future research should examine larger samples across diverse industry contexts and geographic regions to validate findings and identify context-specific considerations.

The rapidly evolving nature of both AI technologies and circular economy practices suggests that continuous research is necessary to maintain relevance and accuracy of findings. Longitudinal studies examining the evolution of AI-enabled circular supply networks over extended time periods would provide valuable insights into maturation patterns and long-term sustainability implications.

The research identifies significant opportunities for investigating emerging technologies including quantum computing, advanced robotics, and biotechnology applications within circular supply contexts. These technological frontiers may enable even more sophisticated optimization capabilities and regenerative approaches that extend beyond current possibilities.

Investigation of policy and regulatory implications represents another important future research direction, particularly regarding the development of supportive frameworks that encourage AI-enabled circular economy transformation while addressing potential risks and unintended consequences. The intersection of technology policy, environmental regulation, and supply chain governance requires comprehensive examination to support effective implementation strategies.

Research into social and ethical implications of AI-driven circular supply networks represents a critical area requiring additional investigation, particularly regarding employment impacts, data privacy considerations, and equitable access to technology benefits. These considerations are essential for ensuring that circular economy transformations contribute to broader social sustainability objectives while avoiding negative externalities.

6. Conclusion

This research demonstrates that intelligent circular supply networks represent a transformative approach to achieving regenerative sustainability through the strategic integration of artificial intelligence technologies with circular economy principles. The findings reveal significant potential for organizations to achieve superior performance across economic, environmental, and social dimensions while building resilience and competitive advantage within increasingly complex operating environments.

The investigation confirms that AI-enabled predictive analytics, autonomous optimization mechanisms, and digital twin applications collectively enable supply network transformations that were previously technically and economically infeasible. Organizations implementing these technologies systematically report substantial improvements in resource efficiency, waste reduction, energy optimization, and stakeholder satisfaction compared to traditional linear approaches.

The research contributes valuable insights regarding implementation strategies, success factors, and performance outcomes that can guide organizational transformation efforts toward circular sustainability models. The demonstrated business cases provide compelling evidence that AI-driven circular supply networks represent economically viable pathways for addressing contemporary sustainability challenges while maintaining operational excellence and competitive positioning.

The implications extend beyond individual organizational benefits to broader systemic transformation potential, suggesting that widespread adoption of AI-enabled circular supply networks could contribute significantly to global sustainability objectives and regenerative economic development. The research provides foundation for continued investigation and development of these transformative approaches as organizations and societies seek solutions to escalating environmental and social challenges.

Future developments in AI technologies, circular economy practices, and regulatory frameworks will likely create additional opportunities for enhancing the performance and impact of intelligent circular supply networks. Organizations developing capabilities in these areas position themselves advantageously for continued innovation and leadership within the evolving sustainability landscape. The transformation toward regenerative business models represents not merely an operational improvement but a fundamental reimagining of how economic systems can create positive value for all stakeholders while respecting planetary boundaries and social equity principles.

References

1. Abualigah, L., Hanandeh, E. S., Zitar, R. A., Thanh, C. L., Khatir, S., & Gandomi, A. H. (2023). Revolutionizing sustainable supply chain management: A review of metaheuristics. *Engineering Applications of Artificial Intelligence*, 126. https://doi.org/10.1016/j.engappai.2023.106839
2. Abushaega, M. M., Moshebah, O. Y., Hamzi, A., & Alghamdi, S. Y. (2024). Multi-objective sustainability optimization in modern supply chain networks: A hybrid approach with federated learning and graph neural networks. *Alexandria Engineering Journal*, 115, 585-602. https://doi.org/10.1016/j.aej.2024.12.048

3. Alinezhad, M., Mahdavi, I., Hematian, M., & Tirkolaee, E. B. (2021). A fuzzy multi-objective optimization model for sustainable closed-loop supply chain network design in food industries. *Environment, Development and Sustainability*, 24(6), 8779-8806. https://doi.org/10.1007/s10668-021-01809-y
4. Bukhari, H., Basingab, M. S., Rizwan, A., Sánchez-Chero, M., Pavlatos, C., More, L. A. V., & Fotis, G. (2025). Sustainable green supply chain and logistics management using adaptive fuzzy-based particle swarm optimization. *Sustainable Computing: Informatics and Systems*, 46. https://doi.org/10.1016/j.suscom.2025.101119
5. Dalal, S., Lilhore, U. K., Simaiya, S., Radulescu, M., & Belascu, L. (2024). Improving efficiency and sustainability via supply chain optimization through CNNs and BiLSTM. *Technological Forecasting & Social Change*, 209. https://doi.org/10.1016/j.techfore.2024.123841
6. Eslamipoor, R., & Sepehriar, A. (2024). Enhancing supply chain relationships in the circular economy: Strategies for a green centralized supply chain with deteriorating products. *Journal of Environmental Management*, 367. https://doi.org/10.1016/j.jenvman.2024.121738
7. Gholizadeh, H., Jahani, H., Abareshi, A., & Goh, M. (2021). Sustainable closed-loop supply chain for dairy industry with robust and heuristic optimization. *Computers & Industrial Engineering*, 157. https://doi.org/10.1016/j.cie.2021.107324
8. Goli, A. (2023). Integration of blockchain-enabled closed-loop supply chain and robust product portfolio design. *Computers & Industrial Engineering*, 179. https://doi.org/10.1016/j.cie.2023.109211
9. Guo, Y., Shi, Q., Guo, C., Li, J., You, Z., & Wang, Y. (2022). Designing a sustainable-remanufacturing closed-loop supply chain under hybrid uncertainty: Cross-efficiency sorting multi-objective optimization. *Computers & Industrial Engineering*, 172. https://doi.org/10.1016/j.cie.2022.108639
10. Hejazi, T. H., & Khorshidvand, B. (2023). Robust optimization of sustainable closed-loop supply chain network considering product family. *Environment, Development and Sustainability*, 26(4), 10591-10621. https://doi.org/10.1007/s10668-023-03166-4

11. Hosseini Dehshiri, S. J., & Amiri, M. (2023). Considering the circular economy for designing closed-loop supply chain under hybrid uncertainty: A robust scenario-based possibilistic-stochastic programming. *Expert Systems With Applications*, 238. https://doi.org/10.1016/j.eswa.2023.121745
12. Iseri, F., Iseri, H., Chrisandina, N. J., Iakovou, E., & Pistikopoulos, E. N. (2025). AI-based predictive analytics for enhancing data-driven supply chain optimization. *Journal of Global Optimization*, 1-28. https://doi.org/10.1007/s10898-025-01509-1
13. Jum'a, L., Ikram, M., & Jose Chiappetta Jabbour, C. (2024). Towards circular economy: A IoT enabled framework for circular supply chain integration. *Computers & Industrial Engineering*, 192. https://doi.org/10.1016/j.cie.2024.110194
14. Khalili-Fard, A., Sabouhi, F., & Bozorgi-Amiri, A. (2024). Data-driven robust optimization for a sustainable steel supply chain network design: Toward the circular economy. *Computers & Industrial Engineering*, 195. https://doi.org/10.1016/j.cie.2024.110408
15. Liu, T., Guan, X., Wang, Z., Qin, T., Sun, R., & Wang, Y. (2024). Optimizing green supply chain circular economy in smart cities with integrated machine learning technology. *Heliyon*, 10(9), e29825. https://doi.org/10.1016/j.heliyon.2024.e29825
16. Nayeri, S., Paydar, M. M., Asadi-Gangraj, E., & Emami, S. (2020). Multi-objective fuzzy robust optimization approach to sustainable closed-loop supply chain network design. *Computers & Industrial Engineering*, 148. https://doi.org/10.1016/j.cie.2020.106716
17. Platon, V., Pavelescu, F. M., Antonescu, D., Constantinescu, A., Frone, S., Surugiu, M., Mazilescu, R., & Popa, F. (2024). New evidence about artificial intelligence and eco-investment as boosters of the circular economy. *Environmental Technology & Innovation*, 35. https://doi.org/10.1016/j.eti.2024.103685
18. Prajapati, D., Jauhar, S. K., Gunasekaran, A., Kamble, S. S., & Pratap, S. (2022). Blockchain and IoT embedded sustainable virtual closed-loop supply chain in E-commerce towards the circular economy. *Computers & Industrial Engineering*, 172. https://doi.org/10.1016/j.cie.2022.108530
19. Ramalingam, S., Subramanian, M., Kumar, B. S., Rushma, S., Tarakaramu, N., Trigui, A.,

Yuldashev, F., Saidani, T., & Khan, M. I. (2025). Blockchain-enhanced optimization for a secure and transparent global energy supply chain with reduced environmental impact and cost. *Egyptian Informatics Journal*, 30. https://doi.org/10.1016/j.eij.2025.100647

20. Richter, L., Lehna, M., Marchand, S., Scholz, C., Dreher, A., Klaiber, S., & Lenk, S. (2022). Artificial Intelligence for Electricity Supply Chain automation. *Renewable and Sustainable Energy Reviews*, 163. https://doi.org/10.1016/j.rser.2022.112459
21. Ruan, M. (2024). The application of multimodal AI large model in the green supply chain of energy industry. *Energy Informatics*, 7(1), 1-31. https://doi.org/10.1186/s42162-024-00402-7
22. Salçuk, K., & Şahin, C. (2022). A novel multi-objective optimization model for sustainable supply chain network design problem in closed-loop supply chains. *Neural Computing and Applications*, 34(24), 22157-22175. https://doi.org/10.1007/s00521-022-07668-6
23. Schultz, F. C., Everding, S., & Pies, I. (2021). Circular supply chain governance: A qualitative-empirical study of the European polyurethane industry to facilitate functional circular supply chain management. *Journal of Cleaner Production*, 317. https://doi.org/10.1016/j.jclepro.2021.128445
24. Shahsavani, I., & Goli, A. (2023). A systematic literature review of circular supply chain network design: application of optimization models. *Environment, Development and Sustainability*, 1-32. https://doi.org/10.1007/s10668-023-03362-2
25. Shambayati, H., Shafiei Nikabadi, M., Saberi, S., & Mardani, A. (2024). A neutrosophic optimization model for supply chain virtualization in the circular economy using the non-dominated sorting genetic algorithm II. *Annals of Operations Research*, 342(1), 687-723. https://doi.org/10.1007/s10479-023-05791-8
26. Shin, Y., Kim, G., & Jeong, Y. (2025). Robust closed-loop supply chain model with return management system for circular economy. *Computers & Industrial Engineering*, 203. https://doi.org/10.1016/j.cie.2025.110993
27. Tajik, M., Yousefi, S., Tosarkani, B. M., & Makui, A. (2025). Digitalization-driven circular economy in battery closed-loop supply chain network design. *Journal of Cleaner Production*, 496.

https://doi.org/10.1016/j.jclepro.2025.145054

28. Tsao, Y. C., Nugraha Ridhwan Amir, E., Thanh, V. V., & Dachyar, M. (2021). Designing an eco-efficient supply chain network considering carbon trade and trade-credit: A robust fuzzy optimization approach. *Computers & Industrial Engineering*, 160. https://doi.org/10.1016/j.cie.2021.107595
29. Xames, M. D., Shefa, J., Azrin, F. A., Uddin, A. S. M. N., Habiba, U., & Zaman, W. (2023). A systematic review of modeling approaches in green supply chain optimization. *Environmental Science and Pollution Research*, 30(53), 113218-113241. https://doi.org/10.1007/s11356-023-30396-w
30. Zhu, J., Yang, L., & Feng, L. (2025). Role of artificial intelligence in mitigating risk in multi-stage agricultural supply chain networks. *Computers & Industrial Engineering*, 207. https://doi.org/10.1016/j.cie.2025.111332