Review

AI Solutions for Sustainable Agricultural Supply Chains

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Abstract: The agricultural supply chain faces mounting sustainability challenges, including resource inefficiencies, climate-induced disruptions, and environmental degradation. Artificial Intelligence (AI) has emerged as a transformative solution, offering predictive analytics, machine learning, and big data tools to optimize agricultural production, streamline logistics, and enhance supply chain resilience. This paper presents a theoretical framework for integrating AI into sustainable food supply chains, emphasizing its role in improving ecological and economic efficiency. Through an extensive literature review, the study explores AI's applications in crop planning, logistics optimization, and supply chain adaptability. It further examines key theoretical foundations, barriers to AI adoption, and strategic approaches to leveraging AI for sustainable development. By bridging AI research with sustainability discourse, this paper provides insights for policymakers, industry leaders, and researchers on strategic AI adoption to foster resilient and low-carbon food supply networks.

Keywords: AI in agriculture; sustainable supply chains; predictive analytics; supply chain resilience; machine learning; logistics optimization; ecological efficiency

1. Introduction

The agricultural sector faces unprecedented challenges in meeting global food demands while simultaneously addressing environmental sustainability concerns. As climate change intensifies, resources deplete, and population growth continues, traditional agricultural supply chain management approaches are proving inadequate to balance ecological preservation with economic viability [1,2]. This pressing need for sustainable agricultural practices has catalyzed the exploration of innovative technological solutions, with artificial intelligence (AI) emerging as a transformative force in reimagining agricultural supply chains.

AI-driven sustainable supply chain management in agriculture represents a rapidly evolving paradigm that leverages computational intelligence to enhance both ecological and economic efficiency [3]. By integrating machine learning algorithms, predictive analytics, and data-driven decision-making processes, agricultural stakeholders can optimize resource utilization, minimize waste, and reduce environmental impacts while maintaining productivity and profitability [4,5]. This technological integration addresses multifaceted challenges ranging from farm-level production inefficiencies to global distribution complexities.

Recent advancements in AI technologies have expanded their application scope across various dimensions of agricultural supply chains. For instance, AI-powered predictive analytics enable more accurate demand forecasting and inventory management, substantially reducing food waste and improving resource allocation efficiency [1,6]. Similarly, AI algorithms facilitate carbon footprint management by analyzing emissions data from transportation, manufacturing, and sourcing activities, thereby identifying key areas for environmental impact reduction [7,8]. Furthermore, AI-enhanced precision agriculture techniques optimize input usage, including water, fertilizers, and pesticides, contributing to more sustainable farming practices [4].

Despite its promising potential, the integration of AI in agricultural supply chains faces significant challenges. Data quality issues, infrastructure limitations, and skill gaps among agricultural professionals hinder widespread adoption. Additionally, ethical concerns regarding data privacy and equitable access to technology necessitate careful consideration and interdisciplinary collaboration. Addressing these challenges requires comprehensive strategic frameworks that guide policymakers and managers in implementing AI solutions that optimize supply chain efficiency while ensuring sustainability and resilience [5,9].

This paper examines the current landscape of AI applications in sustainable agricultural supply chain management, evaluates implementation challenges, and proposes strategic approaches for effective integration. By synthesizing insights from recent research and practice, we aim to provide a holistic understanding of how AI can transform agricultural supply chains to meet the dual objectives of environmental sustainability and economic viability. The following sections examine specific AI applications, implementation frameworks, and future directions for creating robust and sustainable agricultural systems capable of meeting the needs of a growing global population.

2. Background

The role of AI in supply chain management (SCM) is underpinned by several core theories that guide its integration and application. These theories provide a framework for understanding how AI can enhance supply chain efficiency, resilience, and decision-making. The Technology-Organization-Environment (TOE) Framework identifies the drivers, barriers, and outcomes of AI adoption in SCM, emphasizing AI's potential to improve resilience, process efficiency, and sustainability in supply chains [10]. AI Taxonomy categorizes AI applications in SCM into sensing and interacting, learning, and decision-making, forming the basis for current and future research while highlighting the importance of behavioral considerations in AI applications [11]. The Motivation, Application, Capability, and Outcome (MACO) Framework is used to build resilient supply chains through AI, focusing on motivations for AI adoption, its applications, capabilities, and outcomes, providing a practical tool for SCM professionals to optimize operations and resource utilization [12]. Organizational Information Processing Theory (OIPT) conceptualizes AI's role in enhancing supply chain resilience and performance by improving information processing capabilities, which is vital in dynamic and uncertain environments [13]. Mathematical Modeling and Algorithmic Frameworks support supply chain optimization through AI, focusing on demand forecasting, inventory management, and network optimization, with techniques like machine learning, network theory, and game theory being pivotal in strategic decision-making and risk management [14].

The integration of systems thinking, resource-based theory, and sustainability frameworks into AI-driven supply chains is critical for enhancing efficiency, sustainability, and resilience. Systems Thinking in AI-Driven Supply Chains offers a holistic view of supply chain ecosystems, enabling the integration of interdisciplinary relationships and objectives across various stakeholders, helping to align strategic goals with operational processes, thereby enhancing innovation and transformation within supply chains [15]. System dynamics modeling is used to simulate complex supply chain systems, supporting long-term strategic decision-making and integrating environmental and social sustainability metrics [16]. Resource-Based Theory emphasizes the importance of leveraging organizational resources, such as AI technologies, to gain competitive advantages, supporting the selection and integration of resources that enhance supply chain connectivity and information sharing, which are decisive for improving environmental performance [17]. AI technologies are seen as valuable resources that can drive green supply chain management strategies, positively influencing environmental, social, and financial performance [18]. Sustainability Frameworks for AI integration in supply chains primarily address sustainability by focusing on environmental and economic issues, though there is a need to better tackle social aspects like working conditions [19]. Sustainability in supply chains is often studied across multiple dimensions, including environmental, social, and economic factors, and a holistic approach is necessary to integrate these dimensions effectively, ensuring long-term equilibrium and sustainability [20].

The integration of AI in agriculture and logistics is informed by interdisciplinary insights that enhance productivity, sustainability, and efficiency. AI technologies are being applied across various domains within agriculture, including precision farming, supply chain management, and crop monitoring, to address the challenges of a growing global population and environmental sustainability. Precision Agriculture and Resource Management utilize AI technologies such as machine learning, computer vision, and sensor technologies to transform traditional farming practices, providing real-time data and actionable insights for crop monitoring, resource management, and decision support systems, optimizing the use of water, fertilizers, and pesticides [21–23]. In Supply Chain and Logistics, AI improves management by reducing food loss, streamlining logistics, and ensuring timely delivery through data-driven decision-making and predictive analytics, which enhance the efficiency and resilience of the agricultural value chain [24,25]. For Sustainability and Environmental Impact, AI contributes to sustainable farming by minimizing environmental impact through precise resource allocation and management, helping to reduce chemical usage and optimize irrigation strategies, promoting water conservation and reducing environmental runoff [26]. Interdisciplinary Collaboration in the development of AI solutions in agriculture benefits from integrating economic, environmental, social, ethical, and technological perspectives, ensuring that AI applications are robust, economically valuable, and socially desirable, fostering greater acceptance and trust among farmers [27]. Human-Centered AI and Agriculture 5.0 emphasizes the integration of human expertise with AI technologies, balancing technological advancements with human oversight, addressing social, ethical, and legal imperatives, and enhancing decision-making processes [28].

3. Methodology

This study adopts a conceptual research approach, leveraging a systematic literature review to explore the role of AI in sustainable agricultural supply chain management. A structured search strategy was employed to ensure comprehensiveness, transparency, and methodological rigor. The review process involved multiple academic databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar. The search terms included combinations of keywords such as "AI in agriculture," "sustainable supply chains," "machine learning in logistics," "predictive analytics in food supply chains," and "AI-driven supply chain resilience," refined using Boolean operators (AND, OR).

To ensure the quality and relevance of the literature, a set of inclusion and exclusion criteria was applied. Eligible studies were peer-reviewed journal articles and conference proceedings published between 2017 and 2024, written in English, and focused on AI applications within agricultural or food supply chains. Only studies that contributed empirical, theoretical, or conceptual insights into sustainability and supply chain performance were considered. Articles focusing on non-agricultural sectors, lacking a direct AI component, or falling outside peer-reviewed academic standards were excluded. The search initially returned 276 articles. After removing duplicates and screening titles and abstracts, 132 papers were retained for full-text review. Based on the inclusion criteria, 50 articles were ultimately selected for in-depth analysis.

A qualitative content analysis approach was then employed to extract and synthesize key insights from the selected literature. The analysis was organized around four primary thematic categories: (1) AI Technologies in Supply Chain Management, involving the classification of tools such as machine learning, big data analytics, and predictive modeling across agriculture and logistics functions; (2) Sustainability and Efficiency Metrics, examining AI's contribution to reducing carbon emissions, enhancing resource use efficiency, and bolstering resilience; (3) Barriers and Enablers of AI Adoption, identifying technological, economic, regulatory, and organizational factors that affect the implementation of AI; and (4) Theoretical Foundations, which include the integration of key conceptual frameworks such as the Technology-Organization-Environment (TOE) model, Resource-Based Theory, and Organizational Information Processing Theory (OIPT) to contextualize AI's strategic role in sustainability.

The studies were also categorized into seven broader thematic clusters to support further synthesis: predictive analytics and forecasting, resource optimization, logistics and supply chain efficiency, risk and resilience management, food waste reduction and circular economy, human-centered AI and ethics, and policy alignment with sustainability goals. The thematic synthesis of these categories informed the development of a conceptual framework that illustrates the interaction between AI applications, supply chain performance, and sustainability outcomes. This framework provides a theoretical foundation for future empirical research and offers practical guidance for AI integration in sustainable agricultural supply chain strategies.

4. Results and Discussion

4.1. AI Applications in Agricultural Supply Chains

AI is increasingly being integrated into agricultural supply chains to enhance efficiency, sustainability, and resilience. AI-driven predictive analytics significantly improve demand forecasting and supply optimization in agriculture. By leveraging machine learning and big data analytics, AI enhances the accuracy and efficiency of these processes, allowing for better resource allocation and crop planning [29]. AI technologies enable real-time data analysis and predictive maintenance, which are essential for proactive decision-making in agricultural supply chains [30]. AI plays a fundamental role in optimizing logistics and reducing the carbon footprint of food distribution. AI algorithms analyze and optimize carbon emissions across various supply chain stages, including transportation and manufacturing, to identify areas for emission reduction [31]. This approach not only minimizes environmental impact but also enhances operational efficiency through real-time monitoring and predictive analytics [1].

Machine learning and big data analytics contribute to supply chain efficiency by providing real-time insights for decision-making. These technologies improve demand forecasting, inventory management, and logistics processes, leading to reduced lead times and operational costs [32]. AI-driven automation further streamlines tasks such as order processing and route optimization, enhancing overall supply chain reliability [33]. Several case studies demonstrate successful AI integration in food supply chains. For instance, AI-driven models in the USA have been used to reduce carbon footprints in industries like electronic manufacturing and food processing, showcasing practical applications of AI in enhancing operational efficiency and market competitiveness [34]. Also, AI-powered precision agriculture helps increase crop yields while supporting sustainable farming practices [4].

A table summarizing AI Applications in Agricultural Supply Chains categorized by key functional areas is provided (See Table 1):

Table 1. AI Applications Across Agricultural Supply Chain Functions

Supply Chain Area	AI Application	Technologies Used	Sustainability Impact
Crop Planning	Yield prediction, soil analysis, pest forecasting	Machine Learning, Computer Vision, Internet of Things (IoT) Sensors	Improved input use, reduced environmental impact
Inventory Management	Real-time stock tracking, predictive restocking	Predictive Analytics, Radio-Frequency Identification (RFID), Big Data	Reduced food waste, better resource planning
Logistics Optimization	Route planning, transport efficiency, cold chain management	AI Algorithms, Global Positioning System (GPS), IoT	Lower fuel use, emissions reduction
Demand Forecasting	Market trend analysis, seasonal demand prediction	Time-series Machine Learning (ML) models, Big Data Analytics	Minimized overproduction, better pricing strategies
Resource Optimization	Water/fertilizer usage management, energy efficiency	Sensor Networks, AI-based Decision Support Systems	Reduced input waste, cost savings

Risk Management	Climate risk modeling, supply chain disruption prediction	Predictive Modeling, Scenario Simulation	Increased supply chain resilience
Food Waste Reduction	Spoilage prediction, redistribution planning	Image Recognition, AI-Driven Sorting, Blockchain	Enhanced circular economy, minimized loss

4.2. Enhancing Ecological and Economic Efficiency through AI

AI offers promising solutions to enhance both ecological and economic efficiency. By leveraging AI, industries can optimize resource utilization, reduce waste, and improve sustainability across various sectors. AI can enhance economic efficiency while promoting ecological sustainability by optimizing resource allocation, improving monitoring systems, and reducing carbon footprints. AI technologies enable precise resource management in agriculture and waste management, leading to reduced environmental impact and increased economic gains [35]. AI-driven strategies to reduce food waste and optimize resource utilization include Precision Agriculture, where AI helps increase crop yields and reduce the use of fertilizers and pesticides, supporting sustainable farming practices; Supply Chain Optimization, where AI improves food supply chain efficiency by using real-time data and predictive analytics to reduce waste and ensure food quality; and Circular Economy Support, where AI aids in redistributing excess food and enhancing resource efficiency, minimizing environmental impact [36–38].

AI simulations, through predictive analytics and machine learning, help forecast supply chain disruptions, optimize resource allocation, and reduce carbon emissions. These technologies provide actionable insights for sustainable supply chain management [39]. Several metrics and KPIs for evaluating AI's impact on sustainability are proposed. These include Carbon Footprint Reduction, measuring the decrease in emissions due to AI interventions; Resource Efficiency, evaluating improvements in resource utilization and waste reduction; Operational Efficiency, assessing enhancements in supply chain and production processes; and Sustainability Compliance, monitoring adherence to environmental regulations and standards [40–42].

4.3. AI for Resilient and Adaptive Supply Chains

AI plays a key role in enhancing supply chain resilience and adaptability, especially in the face of climate volatility and market uncertainties. However, its implementation also brings certain risks and ethical considerations. Enhancing supply chain resilience against climate volatility is a complex task and it includes Transparency and Customization, where AI enhances supply chain resilience by improving transparency and enabling mass customization of procurement strategies, which helps mitigate the impact of disruptions; Predictive Analytics, where AI technologies like machine learning and predictive analytics allow for real-time risk assessment and response, fortifying supply chains against unforeseen disruptions; Dynamic Capabilities, where AI contributes to developing dynamic capabilities such as visibility, risk management, and agile procurement strategies, which are essential for maintaining resilience during climate-related disruptions; Demand Forecasting and

Inventory Management, where AI improves adaptability by enhancing demand forecasting and inventory management, leading to increased efficiency and flexibility in response to market changes; and Data-Driven Decision Making, where AI adoption facilitates data-driven decision-making, enabling organizations to quickly adapt to market shifts and maintain supply chain agility [43,44].

There are numerous risks and ethical considerations in AI-driven decision-making, too. These include Data Privacy and Security, where the use of AI in supply chains raises concerns about data privacy and security, as sensitive information is processed and analyzed [45]; Bias and Fairness, where AI systems may inadvertently perpetuate biases present in the data, leading to unfair decision-making processes [43]; and Dependence on Technology, where over-reliance on AI could lead to vulnerabilities if the technology fails or is compromised, highlighting the need for robust backup systems and human oversight [46].

4.4. Challenges and Barriers to AI Adoption

Adopting AI in food supply chains presents several challenges across technological, economic, regulatory, and organizational dimensions. These barriers impact the integration of AI technologies and their potential to drive sustainability and efficiency. Technological Barriers include data security, privacy concerns, and the lack of regulations and rules governing AI use. Poor data quality and the need for synergy between AI and human decision-makers also hinder adoption [37]. Economic Barriers refer to the increased cost of implementing AI technologies, such as acquiring intelligent equipment and integrating it with existing systems, which poses significant economic challenges [24]. Regulatory Barriers involve the lack of government support, incentives, and clear policies as significant obstacles. Regulatory compliance and competitor pressure also play vital roles in AI adoption [47]. Data privacy, security, and bias have their impacts, too. Data Privacy and Security concerns are major inhibitors, affecting trust and willingness to adopt AI technologies [31,48].

Bias, including group bias and ethical considerations in AI systems, can undermine efforts to use AI for sustainability, as biased algorithms may lead to unfair or inefficient outcomes [22]. Organizational and cultural challenges are important in adoption decisions. Organizational Challenges, such as resistance to change, lack of knowledge, and the need for skilled personnel are significant barriers. Organizations may struggle with integrating AI into existing workflows and decision-making processes [7]. Cultural Challenges include cultural factors, such as trust in AI systems and the perceived threat to job security, which can impede AI adoption. There is also a need for a culture of innovation and digital competency development [19].

4.5. Strategic Planning for AI Integration in Sustainable Supply Chains

Integrating AI into sustainable supply chains involves strategic planning, policy development, and collaboration. The literature offers insights into policies, alignment with Sustainable Development Goals (SDGs), and strategic partnerships for AI-driven sustainability. The Technology-Organization-Environment (TOE) Framework identifies drivers and barriers to AI adoption in supply chains, emphasizing the need for policies that address technological, organizational, and environmental factors [32]. Regulatory Support involves creating supportive regulatory frameworks that are crucial for AI integration, focusing on data privacy, ethical considerations, and fostering a culture of innovation [47]. Ethical Guidelines include incorporating ethical principles, such as transparency and accountability, which is essential for AI deployment, as recommended by global organizations like United Nations Educational, Scientific and Cultural Organization (UNESCO). Alignment with Sustainable Development Goals (SDGs) is highlighted as a key requirement.

Organizational and Technical Integration shows how AI can drive sustainability by enhancing organizational processes and developing algorithms that address global challenges, contributing to SDGs [48]. Environmental, Social, and Governance (ESG) Performance can be improved by AI, particularly generative AI, by fostering innovation and collaboration in digital supply chains [49,50]. AI and Emotional Intelligence (EQ) integration can enhance educational and healthcare outcomes, aligning with SDGs focused on social well-being [15]. Strategic Partnerships and Collaborations add value, too. Interdisciplinary Collaborations across sectors, such as tourism and manufacturing, can leverage AI for enhanced sustainability and innovation [28]. Resource Orchestration through collaborations that focus on resource management and knowledge sharing can enhance supply chain resilience and sustainability [50]. Digital Ecosystems that build collaborative digital environments can enhance analytical capacities and support the pursuit of SDGs through shared data and insights [32,47].

4.6. Thematic Synthesis and a Conceptual Framework

Across the reviewed studies, several recurring themes emerged. First, predictive analytics and forecasting were widely utilized through machine learning and neural networks to support yield prediction, demand forecasting, and climate risk modeling. These tools enable better alignment between supply and demand, leading to reduced waste and more efficient planning. Second, resource optimization emerged as a dominant theme, where AI-enabled sensor technologies and decision support systems are used in precision irrigation, fertilizer management, and energy use. This leads to significant ecological benefits by minimizing input waste and reducing environmental impact.

Third, the literature strongly supports the role of AI in logistics and supply chain optimization, where real-time routing algorithms and blockchain systems enhance transport scheduling and cold chain integrity, ultimately lowering carbon emissions and improving operational efficiency. Additionally, AI is seen as instrumental in risk and resilience management, where scenario simulation and predictive modeling strengthen supply chain adaptability in the face of disruptions such as climate variability or market shifts.

A notable theme is AI's contribution to the reduction of food waste and support for the circular economy. Technologies like computer vision and AI-driven sorting facilitate spoilage detection and surplus food redistribution, enhancing both sustainability and food security. The synthesis also highlights the growing focus on human-centered AI and ethical considerations, emphasizing the importance of explainable AI and human-in-the-loop systems to build trust, ensure fairness, and encourage responsible technology adoption. Lastly, policy integration and strategic alignment with sustainability goals were prominent, with AI frameworks being used to monitor Environmental, Social, and Governance (ESG) performance and to align with the UN Sustainable Development Goals (SDGs). Together, these themes demonstrate that AI is not merely a technological upgrade but a transformative force that, when thoughtfully integrated, supports ecological efficiency, economic resilience, and inclusive governance in agricultural supply chains.

While not directly linked to AI applications, IoT in agriculture literature can be seen as a precursor to the still upcoming literature on AI in agriculture. IoT technologies are revolutionizing agriculture through interconnected solutions like smart irrigation, precision farming, automated monitoring, and autonomous machinery, creating data-driven operations that enhance productivity, sustainability, and supply chain transparency while reducing waste and improving resource efficiency [50]. There are a lot of similarities, especially in terms of how each of these frames the core debates and implications.

The thematic synthesis of the literature reveals a multi-dimensional understanding of how AI technologies are reshaping sustainable agricultural supply chains. This is summarized in Table 2.

Table 2. A Thematic Synthesis of Literature on AI in Agricultural Supply Chains

Theme	AI Technologies	Applications	Sustainability Outcomes	Representative Studies
Predictive Analytics & Forecasting	Machine Learning, Time-Series Models, Neural Networks	Yield prediction, demand forecasting, climate risk modeling	Reduced waste, better planning, improved market alignment	[1,8,17,29,51]
Resource Optimization	Sensor Technologies, IoT, Decision Support Systems	Precision irrigation, fertilizer optimization, smart greenhouse management	Lower input usage, cost savings, enhanced ecological efficiency	[4,16,22,52]
Supply Chain & Logistics Optimization	AI Routing Algorithms, Real-Time Tracking, Blockchain	Cold chain monitoring, transport scheduling, inventory control	Lower carbon emissions, improved delivery efficiency	[3,7,32,52,53,54]
Risk & Resilience Management	Scenario Simulation, Digital Twins, AI-Driven Decision Support	Disruption forecasting, adaptive sourcing, resilience planning	Improved supply chain adaptability and continuity	[11,26,30,41, 43]
Waste Reduction & Circular Economy	Computer Vision, Predictive Sorting, Redistribution Algorithms	Spoilage detection, surplus redistribution, smart waste tracking	Enhanced circularity, reduced food waste, greater social impact	[2,14,44,46,52]
Human-Centered AI & Ethics	Explainable AI, Human-in-the-loop Systems	Ethical decision-making, augmented expert support, inclusive design	Greater user trust, fairness, and adoption of sustainable practices	[10,28,34,47]
Policy & Strategic Integration	AI-Policy Frameworks, SDG-Mapping Tools	Governance design, performance benchmarking, ESG monitoring	Alignment with sustainability goals, improved regulatory compliance	[17,28,38,49,52, 55]

Based on the above, this study proposes a framework, depicted in Figure 1, that elucidates the interplay between AI applications, supply chain performance, and sustainability outcomes within the agricultural sector. This framework centers on three primary AI-driven mechanisms: Predictive Analytics & Machine Learning, which facilitates improved resource utilization through crop planning, yield prediction, demand forecasting, and inventory optimization; Big Data & IoT Integration, which enhances supply chain transparency and risk management via real-time data analytics; and Automation & Decision Support, which optimizes logistics, transportation, and waste reduction to align with circular economy principles.

These mechanisms subsequently influence three critical performance areas: Improved Agricultural Efficiency, characterized by optimized crop production and resource utilization; Resilient & Adaptive Supply Chains, marked by enhanced risk management and supply chain responsiveness; and Reduced Carbon Footprint, achieved through sustainable logistics and minimized waste generation. Ultimately, the synergistic effect of these elements culminates in Sustainable Food Production, ensuring a harmonious balance between ecological and economic efficiency throughout the agricultural supply chain.

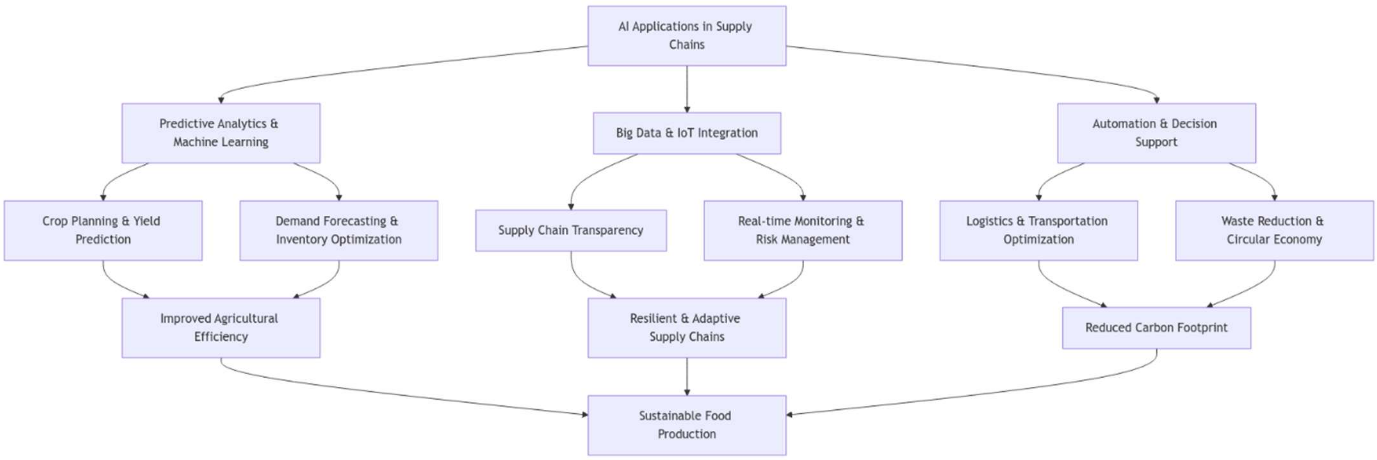

Figure 1. AI in agriculture: A framework highlighting key elements and relationships

5. Conclusion

This study highlights the transformative role of AI in enhancing the sustainability of agricultural supply chains. By leveraging predictive analytics, machine learning, and big data, AI enables improved efficiency, reduced waste, and enhanced resilience against climate and market uncertainties. The theoretical frameworks discussed, including the Technology-Organization-Environment (TOE) model, Resource-Based Theory, and Organizational Information Processing Theory (OIPT), underscore AI's ability to optimize supply chain performance while addressing ecological and economic sustainability challenges. Despite its potential, AI adoption in sustainable food supply chains faces barriers, including technological limitations, economic constraints, regulatory ambiguities, and organizational resistance. Addressing these challenges requires strategic planning, ethical AI governance, and interdisciplinary collaboration. Moreover, AI's integration with sustainability frameworks must consider environmental, social, and economic factors to ensure a balanced and long-term impact.

Future research should explore empirical validations of AI-driven sustainability models, with a focus on real-world implementation challenges and sector-specific case studies. Investigating AI's role in achieving Sustainable Development Goals (SDGs), enhancing supply chain resilience, and mitigating risks such as food insecurity and climate-induced disruptions will be critical. Furthermore, research should examine emerging AI technologies, such as generative AI, blockchain-integrated AI, and quantum computing, to assess their potential in revolutionizing agricultural supply chains.

As AI continues to evolve, its strategic adoption will be essential in fostering sustainable, adaptive, and low-carbon food supply networks. By aligning AI-driven solutions with sustainability goals and ethical considerations, the agricultural sector can navigate global challenges while ensuring food security and environmental responsibility.

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References

1. Elufioye O., Ike C., Odeyemi O., Usman F., & Mhlongo N. AI-driven predictive analytics in agricultural supply chains: a review: assessing the benefits and challenges of ai in forecasting demand and optimizing supply in agriculture. Computer Science & IT Research Journal. 2024, 5(2), 473–497. https://doi.org/10.51594/csitrj.v5i2.817
2. Pal S. Integrating AI in Sustainable Supply Chain Management: A New Paradigm for Enhanced Transparency and Sustainability. International Journal for Research in Applied Science and Engineering Technology. 2023, 11. https://doi.org/10.22214/ijraset.2023.54139
3. Bran F., Bodislav D., Gombos S., & Angheluță S. AI for Sustainable Agribusiness: Innovations and Challenges. European Journal of Sustainable Development. 2024, 13(3), 233. https://doi.org/10.14207/ejsd.2024.v13n3p233
4. Anwar H., Anwar T., & Mahmood G. Nourishing the Future: AI-Driven Optimization of Farm-to-Consumer Food Supply Chain for Enhanced Business Performance. Innovative Computing Review. 2023, 3(2), 14–29. https://doi.org/10.32350/icr.32.02
5. Danach K., Dirani A., & Rkein H. Revolutionizing Supply Chain Management With AI: A Path to Efficiency and Sustainability. IEEE Access. 2024, 12, 188245–188255. https://doi.org/10.1109/ACCESS.2024.3474531
6. Amayreh K. AI-driven agribusiness sustainability: Optimizing supply chains for reduced environmental impact. E3S Web of Conferences. 2025, 614, 03030. https://doi.org/10.1051/e3sconf/202561403030
7. Huang R., & Mao S. Carbon Footprint Management in Global Supply Chains: A Data-Driven Approach Utilizing AI Algorithms. IEEE Access. 2024, 12, 89957–89967. https://doi.org/10.1109/ACCESS.2024.3407839
8. Hasan M., Islam M., Sumon M., Osiujjaman M., Debnath P., & Pant L. Integrating AI and Predictive Analytics in Supply Chain Management to Minimize Carbon Footprint and Enhance Business Growth in the USA. Journal of Business and Management Studies. 2024, 6, 195–212. https://doi.org/10.32996/jbms.2024.6.4.17
9. Shahzadi G., Jia F., Chen L., & John A. AI adoption in supply chain management: a systematic literature review. Journal of Manufacturing Technology Management. 2024, 35, 1125–1150. https://doi.org/10.1108/jmtm-09-2023-0431

10. Dey P., Chowdhury S., Abadie A., Yaroson E., & Sarkar S. Artificial intelligence-driven supply chain resilience in Vietnamese manufacturing small- and medium-sized enterprises. International Journal of Production Research. 2023, 62, 5417–5456. https://doi.org/10.1080/00207543.2023.2179859
11. Kumar S., Raut R., Nayal K., Kraus S., Yadav V., & Narkhede B. To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP. Journal of Cleaner Production. 2021, 293, 126023. https://doi.org/10.1016/J.JCLEPRO.2021.126023
12. Vishwakarma L., Singh R., Mishra R., & Venkatesh M. Exploring the motivations behind AIadoption for building resilient supply chains: a systematic literature review and future research agenda. Journal of Enterprise Information Management. 2024, 37, 1374–1398. https://doi.org/10.1108/jeim-11-2023-0606
13. Belhadi A., Mani V., Kamble S., Khan S., & Verma S. Artificial intelligence-driven innovation for enhancing supply chain resilience and performance under the effect of supply chain dynamism: an empirical investigation. Annals of Operations Research. 2024, 333, 627–652. https://doi.org/10.1007/s10479-021-03956-x
14. Panigrahi R., Shrivastava A., Qureshi K., Mewada B., Alghamdi S., Almakayeel N., Almuflih A., & Qureshi M. AI Chatbot Adoption in SMEs for Sustainable Manufacturing Supply Chain Performance: A Mediational Research in an Emerging Country. Sustainability. 2023, 15, 13743. https://doi.org/10.3390/su151813743
15. Zhao G., Ye C., Dennehy D., Liu S., Harfouche A., & Olan F. (2024). Analysis of barriers to adopting Industry 4.0 to achieve agri-food supply chain sustainability: A group-based fuzzy analytic hierarchy process. Business Strategy and the Environment. 2024, 33, 8559–8586. https://doi.org/10.1002/bse.3928
16. Ameh B. Digital tools and AI: Using technology to monitor carbon emissions and waste at each stage of the supply chain, enabling real-time adjustments for sustainability improvements. International Journal of Science and Research Archive. 2024, 13, 2741–2754. https://doi.org/10.30574/ijsra.2024.13.1.1995
17. Louis N.E. Leveraging AI for enhanced supply chain optimization. Open Access Research Journal of Multidisciplinary Studies. 2024, 7, 1–15. https://doi.org/10.53022/oarjms.2024.7.2.0044
18. Singh D., Sharma A., Singh R., & Rana P. Augmenting supply chain resilience through AI and big data. Business Process Management Journal. 2025, 31, 631–657. https://doi.org/10.1108/bpmj-04-2024-0260
19. Hao X., & Demir E. AI in supply chain decision-making: an environmental, social, and governance triggering and technological inhibiting protocol. Journal of Modelling in Management. 2024, 19, 605–629. https://doi.org/10.1108/jm2-01-2023-0009
20. Nuerk J., & Dařena F. Activating supply chain business models' value potentials through Systems Engineering. Systems Engineering. 2023, 26, 660–674. https://doi.org/10.1002/sys.21676
21. Singh R., Modgil S., & Shore A. Building AIenabled resilient supply chain: a multi-method approach. Journal of Enterprise Information Management. 2024, 37, 414–436. https://doi.org/10.1108/jeim-09-2022-0326
22. Del Río Castro G., Fernández M., & Colsa Á. Unleashing the convergence amid digitalization and sustainability towards pursuing the Sustainable Development Goals (SDGs): A holistic review. Journal of Cleaner Production. 2021, 280, 122204. https://doi.org/10.1016/J.JCLEPRO.2020.122204
23. Dora M., Kumar A., Mangla S., Pant A., & Kamal M. Critical success factors influencing AIadoption in food supply chains. International Journal of Production Research. 2021, 60, 4621–4640. https://doi.org/10.1080/00207543.2021.1959665
24. Gupta S., Modgil S., Meissonier R., & Dwivedi Y. AI and Information System Resilience to Cope With Supply Chain Disruption. IEEE Transactions on Engineering Management. 2024, 71, 10496–10506. https://doi.org/10.1109/TEM.2021.3116770
25. Cubric M. Drivers, barriers and social considerations for AI adoption in business and management: A tertiary study. Technology in Society. 2020, 62, 101257. https://doi.org/10.1016/j.techsoc.2020.101257
26. Abaku G., Abaku E., Edunjobi T., & Odimarha A. Theoretical approaches to AI in supply chain optimization: Pathways to efficiency and resilience. International Journal of Science and Technology Research Archive. 2024, 6, 92–107. https://doi.org/10.53771/ijstra.2024.6.1.0033
27. Qu C., & Kim E. Reviewing the Roles of AI-Integrated Technologies in Sustainable Supply Chain Management: Research Propositions and a Framework for Future Directions. Sustainability. 2024, 16, 6186. https://doi.org/10.3390/su16146186
28. Bag S., Gupta S., Kumar S., & Sivarajah U. Role of technological dimensions of green supply chain management practices on firm performance. Journal of Enterprise Information Management. 2021, 34, 1–27. https://doi.org/10.1108/jeim-10-2019-0324

29. Sinha M., Dasgupta T., & Mitra A. AI and Data-driven Approaches for Agriculture. Proceedings of the 15th Annual Meeting of the Forum for Information Retrieval Evaluation. 2024, 158–159. https://doi.org/10.1145/3632754.3632946
30. Trabelsi M., Casprini E., Fiorini N., & Zanni L. Unleashing the value of AI in the agri-food sector: where are we? British Food Journal. 2023, 12, 482–515. https://doi.org/10.1108/bfj-11-2022-1014
31. Mishra A., Das J., & Awtar R. An Emerging Era of Research in Agriculture Using AI. Journal of Scientific Research and Technology. 2024, 2, 1–7. https://doi.org/10.61808/jsrt93
32. Babu S., & Mohan U. An integrated approach to evaluating sustainability in supply chains using evolutionary game theory. Computers & Operations Research. 2018, 89, 269–283. https://doi.org/10.1016/j.cor.2017.01.008
33. Yap C., Leow C., & Leong W. Deployment of Industry 4.0 into the Agricultural Food Industry: A Focus on Facet, Insight, Knowledge, and Resilience (FIKR) Personality Traits and AI-Powered Inventory Management. Food Science and Engineering. 2024, 5, 337–344. https://doi.org/10.37256/fse.5220243707
34. Ryan M., Isakhanyan G., & Tekinerdogan B. An interdisciplinary approach to AI in agriculture. NJAS: Impact in Agricultural and Life Sciences. 2023, 95, 2168568. https://doi.org/10.1080/27685241.2023.2168568
35. Rebs T., Brandenburg M., & Seuring S. System dynamics modeling for sustainable supply chain management: A literature review and systems thinking approach. Journal of Cleaner Production. 2019, 208, 1265–1280. https://doi.org/10.1016/J.JCLEPRO.2018.10.100
36. Gupta C., Kumar V., & Khurana A. AI integration with the supply chain, making it green and sustainable. 2023 7th International Conference on Electronics, Materials Engineering & Nano-Technology (IEMENTech). 2023, 1–5. https://doi.org/10.1109/IEMENTech60402.2023.10423506
37. Modgil S., Singh R., & Hannibal C. AI for supply chain resilience: learning from Covid-19. The International Journal of Logistics Management. 2022, 33, 1246–1268. https://doi.org/10.1108/ijlm-02-2021-0094
38. Razak S., Yogarayan S., Sayeed M., & Derafi M. Agriculture 5.0 and Explainable AI for Smart Agriculture: A Scoping Review. Emerging Science Journal. 2024, 8, 744–760. https://doi.org/10.28991/esj-2024-08-02-024
39. Wang S., & Zhang H. Promoting sustainable development goals through generative AIin the digital supply chain: Insights from Chinese tourism SMEs. Sustainable Development. 2024, 33, 1231–1248. https://doi.org/10.1002/sd.3152
40. Cinar A., & Bilodeau S. Incorporating AI into the Inner Circle of Emotional Intelligence for Sustainability. Sustainability. 2024, 16, 6648. https://doi.org/10.3390/su16156648
41. Pournader M., Ghaderi H., Hassanzadegan A., & Fahimnia B. AI applications in supply chain management. International Journal of Production Economics. 2021, 241, 108250. https://doi.org/10.1016/J.IJPE.2021.108250
42. Shibin K., Dubey R., Gunasekaran A., Hazen B., Roubaud D., Gupta S., & Foropon C. Examining sustainable supply chain management of SMEs using resource based view and institutional theory. Annals of Operations Research. 2017, 290, 301–326. https://doi.org/10.1007/s10479-017-2706-x
43. Elbasi E., Mostafa N., AlArnaout Z., Zreikat A., Cina E., Varghese G., Shdefat A., Topcu A., Abdelbaki W., Mathew S., & Zaki C. AI Technology in the Agricultural Sector: A Systematic Literature Review. IEEE Access. 2023, 11, 171–202. https://doi.org/10.1109/ACCESS.2022.3232485
44. Daraojimba D., Adewusi A., Asuzu O., Olorunsogo T., Iwuanyanwu C., & Adaga E. AI in precision agriculture: A review of technologies for sustainable farming practices. World Journal of Advanced Research and Reviews. 2024, 21, 2276–2285. https://doi.org/10.30574/wjarr.2024.21.1.0314
45. Holzinger A., Fister I., Kaul H., & Asseng S. Human-Centered AI in Smart Farming: Toward Agriculture 5.0. IEEE Access. 2024, 12, 62199–62214. https://doi.org/10.1109/ACCESS.2024.3395532
46. Sharma R., Kamble S., Gunasekaran A., Kumar V., & Kumar A. A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. Computers & Operations Research. 2020, 119, 104926. https://doi.org/10.1016/j.cor.2020.104926
47. Jones J., Harris E., Febriansah Y., Adiwijaya A., & Hikam I. AI for Sustainable Development: Applications in Natural Resource Management, Agriculture, and Waste Management. International Transactions on AI(ITALIC). 2024, 2, 143–149. https://doi.org/10.33050/italic.v2i2.549
48. Ifesinachi A., Sodiya E., Jacks B., Ugwuanyi E., Adeyinka M., Umoga U., Daraojimba A., & Lottu O. Reviewing the role of AI and machine learning in supply chain analytics. GSC Advanced Research and Reviews. 2024, 18, 312–320. https://doi.org/10.30574/gscarr.2024.18.2.0069

49. Onyeaka H., Tamasiga P., Nwauzoma U., Miri T., Juliet U., Nwaiwu O., & Akinsemolu A. Using AI to Tackle Food Waste and Enhance the Circular Economy: Maximising Resource Efficiency and Minimising Environmental Impact: A Review. Sustainability. 2023, 15, 10482. https://doi.org/10.3390/su151310482
50. Betty O.A., Arowosegbe O., Ballali C., Kofi K., Adeshina M., Agbelusi J., & Adeshina M. Combating food waste in the agricultural supply chain: A systematic review of supply chain optimization strategies and their sustainability benefits. World Journal of Advanced Research and Reviews. 2024, 24, 122–140. https://doi.org/10.30574/wjarr.2024.24.1.3023
51. Kumar V., Sharma K.V., Kedam N., Patel A., Kate T.R. and Rathnayake U. A comprehensive review on smart and sustainable agriculture using IoT technologies. Smart Agricultural Technology. 2024, 8, 100487. https://doi.org/10.1016/j.atech.2024.100487
52. Hasan M., Rabbi R., Rahman A., Mukaddim A., Khan M., Hider M., & Zeeshan M. Optimizing Sustainable Supply Chains: Integrating Environmental Concerns and Carbon Footprint Reduction through AI-Enhanced Decision-Making in the USA. Journal of Economics, Finance and Accounting Studies. 2024, 6, 57–71.https://doi.org/10.32996/jefas.2024.6.4.7
53. Kulkov I., Kulkova J., Rohrbeck R., Menvielle L., Kaartemo V., & Makkonen H. AI-driven sustainable development: Examining organizational, technical, and processing approaches to achieving global goals. Sustainable Development. 2023, 32, 2253–2267. https://doi.org/10.1002/sd.2773
54. Bidin M., Espinosa-Jaramillo M., Martínez D., Amri N., Hashim N., Chauhan S., & Karmode S. Adaptive Supply Chain Risk Management Using AI Mitigating Disruptions and Enhancing Resilience in the Post-Pandemic Era. Tuijin Jishu/Journal of Propulsion Technology. 2024, 45, 2655–2664. https://doi.org/10.52783/tjjpt.v45.i02.6294
55. George B. and Paul J. Digital transformation in business and society. Springer International Publishing: New York, NY, USA, 2020.