Journal of Agro Complex Development Society
Vol 2(2) October 2025
https://agrocomplex.professorline.com/index.php/journal/index

E-Commerce Logistics Integration for Sustainable Agricultural Value Chains Toward a Digital Green Supply System

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Abstract
The rapid expansion of e-commerce logistics has transformed agricultural value chains, creating new opportunities for efficiency, traceability, and sustainability. However, the integration of logistics systems with sustainable agriculture remains limited in both practice and policy. This study develops a conceptual framework called the Digital Green Supply System (DGSS) by extending the model proposed by Zhou et al. (2024) on optimal logistics strategies for green agricultural e-commerce. Using a theory-extension approach based on secondary quantitative findings and system-level interpretation, the research explores how digital logistics can serve as a catalyst for sustainable agricultural transformation. The analysis reinterprets key parameters game-theoretic model logistics service cost coefficient (k), consumer sensitivity to logistics quality (γ), and platform commission rate (ρ) to explain how cost–service trade-offs influence environmental and economic outcomes. The proposed DGSS framework comprises four interconnected layers: digital integration, green logistics, value chain optimization, and sustainability feedback. Together, these components form an adaptive ecosystem that balances profitability, carbon efficiency, and social inclusivity through data-driven coordination and real-time feedback loops. The findings highlight that e-commerce logistics integration can reduce post-harvest losses, lower emissions, and enhance market accessibility for rural producers. Policy implications include promoting green logistics subsidies, digital infrastructure investment, and open data systems to strengthen environmental accountability. Overall, the DGSS framework positions e-commerce logistics as both a strategic enabler of sustainable agriculture and a foundation for low-carbon, resilient, and inclusive agri-food systems.

Keywords: e-commerce logistics; sustainable agriculture; green supply chain; digital integration; circular economy; value chain sustainability.

1. Introduction

Agriculture has entered a period of structural transformation driven by digitalization, sustainability imperatives, and global market integration. The emergence of e-commerce logistics has revolutionized the way agricultural products are distributed, consumed, and valued [1]. As online platforms increasingly mediate transactions between farmers and consumers, logistics has evolved from a background operational function into a central driver of competitiveness and sustainability. This convergence of digital technology and logistics infrastructure has the potential to create what may be called a Digital Green Supply System (DGSS), a system in which information, goods, and sustainability goals flow seamlessly across the agricultural value chain [2].

In developing economies, particularly in Asia, the rapid growth of agricultural e-commerce has redefined how smallholder farmers access markets. Platforms such as Pinduoduo, Alibaba Rural Taobao, and Tokopedia have allowed producers to bypass traditional intermediaries, reducing transaction costs and improving price transparency [3]. Yet, while e-commerce facilitates connectivity, logistics remain the critical bottleneck especially for perishable and eco-certified products. The efficiency, environmental impact, and cost structure of logistics determine not only the profitability of e-commerce-based agriculture but also its long-term contribution to sustainable development [4].

Recent studies have emphasized that the integration of green logistics principles including low-carbon transportation, smart routing, renewable energy use, and waste minimization is essential to align agricultural e-commerce with sustainability goals (Zhou et al., 2024). Unlike traditional agricultural supply chains, which prioritize cost and speed, sustainable e-commerce logistics seeks to balance economic efficiency, environmental stewardship, and social inclusion [5]. This balance requires data-driven coordination across producers, platforms, and consumers, supported by digital technologies such as the Internet of Things (IoT), blockchain traceability, and artificial intelligence in logistics optimization [6].

The study by Zhou et al. (2024) offers a significant advancement in understanding how logistics strategies can be optimized in the context of e-commerce for green agricultural products. Using a game-theoretic model, the authors compared three logistics service formats-managed, third-party, and platform-managed and analyzed their impact on pricing, service quality, and sustainability. Their findings show that logistics service cost coefficients, consumer sensitivity to logistics quality, and platform commission rates jointly determine the optimal balance between profitability and ecological performance. Platform-managed logistics systems emerge as the most sustainable when integrated digital coordination and environmental control are prioritized. This insight underscores the need for logistics integration not merely as an operational choice, but as a strategic sustainability mechanism in modern agricultural value chains [6].

The implications of such integration extend beyond logistics efficiency. In a digital agricultural ecosystem, logistics decisions influence multiple sustainability dimensions energy consumption, carbon emissions, packaging waste, and post-harvest losses. Poorly designed logistics networks can negate the environmental benefits of organic or low-carbon farming by increasing transportation intensity or cold-chain inefficiencies [7]. Conversely, a digitally integrated logistics model one that uses real-time data for demand forecasting, route optimization, and warehouse coordination can transform the agricultural supply chain into a circular and adaptive system. Through these digital feedback loops, logistics become both a coordination tool and a sustainability instrument, capable of aligning production, distribution, and consumption with environmental goals [8].

Moreover, the integration of e-commerce logistics contributes to inclusive economic growth by connecting smallholder farmers to higher-value markets. By digitizing the flow of goods and information, rural producers can participate directly in global agri-food systems without the need for intermediaries. However, the absence of efficient logistics networks often prevents rural participation, leading to uneven benefits of digital transformation [8]. The establishment of green logistics platforms supported by shared infrastructure, collaborative transportation models, and transparent pricing can therefore reduce rural exclusion and enhance equitable access to e-commerce benefits. This transformation is particularly relevant to countries like Indonesia, where agriculture employs a significant portion of the population and logistics inefficiency accounts for a large share of product loss and cost inflation [9].

At a theoretical level, integrating e-commerce logistics with sustainable agriculture represents a convergence of two major paradigms: digitalization and ecological modernization. Digitalization provides the technical capacity to collect, process, and analyze real-time data, while ecological modernization offers the normative framework to guide these technologies toward sustainability objectives. When combined, they create an intelligent supply chain capable of monitoring environmental performance, adjusting operations dynamically, and optimizing energy use. In this configuration, data becomes the connective tissue of sustainability linking decisions at the farm, logistics, and market levels into one integrated system [10].

However, achieving such integration requires a systemic understanding of trade-offs. As Zhou et al. (2024) highlight, improving logistics quality often increases operational costs and energy consumption, potentially undermining sustainability unless offset by efficiency gains. Therefore, the challenge lies not only in introducing green logistics technologies but in designing coordinated decision frameworks where economic incentives align with environmental goals. Game-theoretic modeling provides a useful analytical lens for understanding these interactions, but practical implementation demands collaboration between farmers, platforms, policymakers, and logistics firms [11].

This study builds upon Zhou et al's framework and extends its application to the broader context of sustainable agricultural value chain integration. By reinterpreting the equilibrium relationships between cost, quality, and sustainability, the concept of the Digital Green Supply System (DGSS) is proposed as a comprehensive model that links digital logistics integration with the principles of sustainable agriculture. The DGSS envisions an ecosystem where e-commerce platforms act as sustainability orchestrators not only facilitating trade but also optimizing carbon efficiency, waste reduction, and resource circulation throughout the supply chain [12].

In summary, the transformation of agricultural e-commerce into a digital green system is not simply an economic upgrade but an environmental necessity. As the agricultural sector faces increasing pressure to reduce emissions and ensure food security, integrating e-commerce logistics with sustainable agricultural practices offers a practical pathway toward inclusive, resilient, and low-carbon food systems. The remainder of this paper elaborates on the theoretical basis, model adaptation from Zhou et al. (2024), and implications for future agricultural logistics design under the Digital Green Supply System paradigm.

2. Methods

2.1 Data Source

This study relies on secondary quantitative and theoretical data derived from Zhou et al. (2024), Optimal Logistics Service Strategies in Green Agricultural Product Supply Chains with E-Commerce Platforms, published in Sustainable Operations and Computers. The source paper develops a game-theoretic optimization model to evaluate how e-commerce platforms, logistics providers, and agricultural producers interact strategically under varying levels of cost, service quality, and consumer preferences [6].

The model compares three logistics configurations self-managed logistics, third-party logistics (3PL), and platform-managed logistics to determine equilibrium outcomes for pricing, service quality, and sustainability performance. Zhou et al. (2024) use mathematical derivations, numerical simulations, and sensitivity analyses to explore how logistics service cost coefficients (k), commission rates (ρ), and consumer sensitivity to logistics quality (γ) influence profit distribution and carbon efficiency [6].

To this conceptual study, the Zhou et al. dataset and equations serve as a reference system to explore how digital logistics strategies can be integrated into sustainable agricultural value chains. Rather than replicating empirical modeling, this research extends their theoretical findings into a broader framework of Digital Green Supply Systems (DGSS), a model that emphasizes not only cost and service optimization but also environmental and social outcomes in agricultural e-commerce.

2.2 Analytical Framework

The analytical process adopts a theory-extension methodology, which combines quantitative logic from Zhou et al.'s model with sustainability-oriented systems thinking. The analysis follows three sequential stages [13]:

- Model Interpretation:

  The mathematical outcomes of Zhou et al.'s game-theoretic model are analyzed qualitatively to extract underlying behavioral patterns among supply chain actors—specifically, how variations in cost, logistics service level, and consumer demand shape equilibrium strategies.

- Sustainability Integration:

These behavioral patterns are reinterpreted through the lens of sustainable agriculture and circular economy theory. Key sustainability indicators such as carbon emissions, energy efficiency, and resource utilization are conceptually mapped to the logistics strategies analyzed in Zhou et al. (2024).

- Framework Development:

Insights from both stages are synthesized into a Digital Green Supply System (DGSS) Framework, representing the integration of e-commerce logistics, digital coordination, and sustainable agricultural production. The framework illustrates how information feedback loops, renewable energy logistics, and traceable supply systems jointly contribute to resilient and low-carbon agricultural ecosystems.

2.3 Analytical Tools and Logic

Although this study does not conduct empirical computation, it adopts Zhou et al.'s theoretical decision parameters logistics cost coefficient (k), service sensitivity (γ), and commission rate (ρ) as conceptual anchors to model trade-offs among economic, environmental, and social dimensions. These parameters serve as proxies for three critical system variables [14]:

- Economic Efficiency: Operational cost minimization and service optimization.
- Environmental Sustainability: Reduction in logistics-related emissions and resource waste.
- Social Inclusivity: Enhanced participation of smallholder farmers through digital access and platform transparency.

The analytical reasoning draws upon comparative simulation logic: under what theoretical conditions does logistics integration yield optimal sustainability outcomes? This reasoning enables the adaptation of Zhou et al.'s model into a normative design tool for sustainable agricultural logistics planning.

Graphical synthesis and model adaptation were supported by qualitative mapping techniques, using flow diagrams to represent causal linkages among logistics structure, digital feedback mechanisms, and sustainability outputs. This visual translation transforms mathematical equilibrium models into actionable sustainability frameworks.

2.4 Limitations

The study acknowledges the inherent limitation of relying on a single-source model. Zhou et al. (2024) primarily address cost and service optimization rather than direct environmental externalities such as carbon accounting or waste reduction. As such, the extension into a Digital Green Supply System introduces conceptual interpretation beyond the model's original scope. Nevertheless, this approach remains valid for theory-building research, offering a strategic synthesis that bridges quantitative optimization and sustainable development paradigms.

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3. Results and Proposed Model

3.1 Reinterpreting Zhou et al.'s Findings: The Strategic Role of Logistics Integration

Zhou et al. (2024) provides strong evidence that logistics decisions are the central lever shaping sustainability and profitability in agricultural e-commerce. Their game-theoretical analysis demonstrates that equilibrium outcomes depend on three interrelated parameters: the logistics service cost coefficient (k), the consumer sensitivity to service quality (γ), and the platform commission rate (ρ).

When logistics costs are low, third-party logistics (3PL) systems dominate because they achieve economies of scale in transport and distribution. However, as costs increase, the model predicts a structural shift toward platform-managed or self-managed logistics, which allows better control over both service quality and environmental impact. This transition implies a fundamental insight: digital coordination reduces the marginal cost of sustainability. Through platform integration, data on demand, temperature control, and routing are optimized simultaneously, creating economic and ecological synergies.

In the context of sustainable agriculture, these dynamic highlights the role of information symmetry when producers, logistics providers, and consumers share data transparently, they can align operational efficiency with environmental targets. For example, the same algorithm that minimizes delivery time can also minimize carbon intensity per delivery unit, turning economic efficiency into an ecological advantage.

3.2 The Digital Green Supply System (DGSS) Framework

Based on Zhou et al's theoretical outcomes, this study extends their model into a broader conceptual structure called the Digital Green Supply System (DGSS). DGSS represents an integrated ecosystem where e-commerce logistics, digital technology, and sustainable agricultural practices are functionally interconnected.

Figure 1 illustrates this system, structured in four dynamic layers

Figure 1 illustrates the Digital Green Supply System (DGSS) as an integrated framework that connects digital platforms, logistics innovation, and sustainable agricultural value chains. The model consists of four interactive layer digital integration, green logistics, value chain optimization, and sustainability feedback each functioning as a core mechanism within a continuous improvement cycle.

At the base, the Digital Integration Layer links farmers, e-commerce platforms, and consumers through data connectivity. This digital interface enables real-time communication of demand, inventory, and logistics information, ensuring that production and delivery decisions are synchronized. The Green Logistics Layer builds upon this by incorporating technologies such as smart routing, electric or renewable-powered vehicles, and biodegradable packaging, reducing emissions and minimizing waste throughout the delivery process.

The Value Chain Optimization Layer acts as the system's operational core. Through digital warehousing, AI-assisted forecasting, and blockchain-based traceability, this layer balances economic efficiency with environmental performance. It ensures that agricultural products move through the supply chain with minimal resource waste while maintaining service quality and profitability. Finally, the Sustainability Feedback Layer functions as the adaptive engine of the DGSS. Data collected across systems such as carbon metrics, cost efficiency, and consumer behavior is analyzed and fed back into the network to continuously refine logistics strategies and sustainability outcomes.

Overall, the DGSS framework visualizes how e-commerce logistics can evolve into a self-learning, low-carbon ecosystem that harmonizes technology, efficiency, and sustainability. It highlights that the path to a greener agricultural future lies not only in production innovation but also in the intelligent integration of digital logistics systems that connect every stage of the agricultural value chain.

3.3 Economic–Environmental Trade-offs and Synergies

A core insight from Zhou et al. (2024) is that sustainability and profitability need not be conflicting goals. Their sensitivity analysis shows that when consumer awareness and willingness to pay for green logistics increase, both sellers and platforms benefit from investing in higher service quality. This finding challenges the conventional belief that environmental upgrades necessarily reduce competitiveness.

In the DGSS perspective, economic and environmental outcomes are co-dependent:

- The marginal cost of upgrading to green logistics (e.g., renewable-powered transport) decreases as digital platforms expand and aggregate demand.
- Profit margins improve as eco-conscious consumers reward sustainable practices with loyalty and price premiums.
- The efficiency of logistics enabled by big data and AI reduces idle time, waste, and overproduction, indirectly supporting low-carbon goals.
- Thus, a properly designed DGSS aligns market logic with ecological logic, translating sustainability from an external obligation into an internal performance metric.

3.4 Social Inclusivity and Rural Integration

One of the most underappreciated outcomes of digital logistics integration is its effect on social inclusivity. Traditional agricultural logistics often exclude smallholders because of high entry costs, lack of access to cold chains, and weak bargaining power with intermediaries. E-commerce platforms, however, can function as social equalizers by offering digital access to logistics services, transparent pricing, and real-time performance tracking. In a DGSS model, rural cooperatives can form aggregated nodes in the logistics network acting as micro-hubs for storage, processing, and delivery coordination. This arrangement reduces transportation distance per farmer, lowers collective emissions, and enhances traceability. By embedding smallholders into platform-based ecosystems, e-commerce logistics become not just a business model but a mechanism of rural empowerment.

Moreover, digital traceability systems (such as blockchain-based product tracking) build consumer trust and validate environmental claims, strengthening the social dimension of sustainability: transparency, accountability, and ethical trade.

3.5 Toward a Circular and Adaptive Agricultural Economy

The synthesis of Zhou et al’s model and DGSS principles points toward a transformation in how agricultural logistics systems operate. Instead of pursuing linear “farm-to-market” efficiency alone, future supply chains should operate as circular, adaptive networks recycling data, materials, and energy to sustain long-term ecological balance.

Digital technologies make this transformation possible. IoT sensors provide temperature and carbon data in real time; AI analytics identify optimal transport routes; and cloud-based platforms connect distributed actors into a unified decision network. Over time, these technologies create adaptive intelligence, a system that continuously improves its own sustainability metrics.

In this configuration, e-commerce logistics acts as both an economic conductor and an environmental regulator. Every delivery, transaction, and feedback loop contributes to the larger goal of carbon-neutral, resource-efficient, and socially equitable agriculture.

4. Discussion

4.1 Strategic Implications: Digital Logistics as the Backbone of Green Agriculture

The Digital Green Supply System (DGSS) redefines logistics not as a supportive function but as a strategic backbone of sustainability. In the agricultural context, logistics integration influences nearly every sustainability dimension from input efficiency and carbon emissions to farmer livelihoods and market accessibility. Zhou et al. (2024) emphasized that the coordination power of e-commerce platforms can align the incentives of diverse actors in the supply chain. Within the DGSS framework, this coordination transforms into collaborative intelligence, where real-time data and algorithmic decision-making optimize both profitability and environmental performance simultaneously [12].

The strategic implication is clear: in digital agriculture, logistics is the new field of cultivation. Data, rather than land, becomes the key resource that determines system productivity. Through digital integration, smallholder farmers traditionally fragmented and isolated gain access to a coordinated logistics network that amplifies their market presence while reducing ecological footprint. When logistics platforms incorporate environmental monitoring and carbon reporting tools, they become instruments of ecological accountability, linking every kilometer travel to measurable sustainability outcomes [15].

4.2 Environmental Dimension: Low-Carbon Transition through E-Commerce Logistics

Incorporating e-commerce logistics into the agricultural value chain offers a direct pathway to decarbonizing rural supply systems. Transportation and post-harvest losses represent major sources of agricultural emissions, particularly in developing economies where cold chains are inefficient. DGSS addresses this by embedding green logistics technologies with renewable-powered vehicles, optimized routes, and temperature-controlled systems that minimize waste and energy use [16].

Zhou et al.’s (2024) sensitivity analysis shows that when logistics service quality is improved alongside consumer awareness of sustainability, the equilibrium outcome supports both profit and emission reduction. This finding can be extrapolated to a systemic level: when e-commerce logistics are digitally managed, sustainability becomes a by-product of efficiency. Algorithmic optimization once aimed solely at cost reduction can now be recalibrated to also minimize carbon intensity per transaction [17].

Moreover, the digitalization of logistics allows traceable environmental accounting. Blockchain or cloud-based platforms can record emissions data, transportation energy use, and product provenance, enabling certification and consumer trust. Such transparency transforms sustainability from a marketing slogan into a quantifiable, verifiable process embedded within daily logistics operations.

4.3 Economic and Institutional Integration: Aligning Incentives for Green Growth

A sustainable logistics system cannot operate in isolation it requires institutional integration and policy alignment. The DGSS framework suggests that e-commerce platforms can serve as intermediaries between agricultural producers and regulatory institutions, providing data infrastructures for environmental monitoring, carbon credits, and eco-certification. Governments can leverage this digital transparency to design incentive mechanisms, such as green logistics subsidies, low-interest loans for renewable energy transport, or carbon tax credits tied to verified reductions [18].

From an economic perspective, the convergence of e-commerce and sustainable agriculture opens a new domain of green entrepreneurship. Farmers who adopt platform-based logistics can diversify income streams by offering services such as on-demand cold storage, localized packaging, or shared distribution models. The Zhou et al. (2024) equilibrium outcomes indicate that as logistics costs decrease through digital efficiency, small producers can reinvest savings into sustainable inputs, creating a virtuous cycle of reinvestment and innovation [19].

Furthermore, by aggregating logistics data across regions, e-commerce platforms can perform predictive analytics that help governments forecast agricultural supply, prevent food waste, and design more resilient distribution policies. This positions digital logistics not only as a market tool but as an instrument of governance and sustainability planning.

4.4 Social and Rural Development Implications

Beyond economics and ecology, the DGSS model carries profound social implications for rural transformation. Rural areas often face logistical exclusion due to geographic dispersion and limited infrastructure. E-commerce integration bridges this divide by establishing digital corridors virtual networks of farmers, consumers, and logistics providers that bypass traditional market barriers. In practical terms, digital logistics hubs located in rural regions can act as empowerment centers where farmers access shared cold storage, information services, and online distribution channels [20]. Zhou et al.'s insights about shifting logistics preferences from third-party to self-managed or platform-managed systems reflect a broader trend toward local autonomy and technological empowerment. When localized logistics nodes are supported by digital platforms, they generate employment, build skills, and foster innovation at the community level [21].

This process strengthens rural social capital, as cooperation replaces competition, and sustainability becomes a shared mission rather than an imposed regulation. Digital tools (e.g., mobile order tracking, collective apps for inventory) help farmers participate directly in the digital economy while maintaining environmental responsibility. The DGSS thus acts as a social infrastructure for inclusion, turning data access and green logistics into public goods that serve collective development goals [22].

4.5 Theoretical Contribution: From Optimization to Systems Thinking

The integration of Zhou et al.'s model into the DGSS framework marks a conceptual shift from optimization to systems thinking. While game-theoretic modeling offers precision in identifying equilibrium outcomes, sustainability requires understanding how multiple equilibria evolve dynamically over time. In real-world agricultural ecosystems, actors do not merely react to cost and service parameters they co-adapt through learning, policy, and innovation [23].

The DGSS extends this logic by incorporating feedback loops, where logistics performance data continuously inform production and policy decisions. This circular reasoning mirrors the principles of adaptive systems theory, in which complex networks self-organize to maintain balance between efficiency and resilience. Thus, the DGSS transforms static equilibrium into dynamic sustainability where each transaction contributes to the system's long-term stability [24].

The theoretical contribution of this approach lies in framing logistics integration as a living system not merely a chain of deliveries but a web of socio-technical relationships that collectively determine agricultural sustainability. It situates e-commerce logistics at the intersection of economics, ecology, and sociology, offering a multi-disciplinary model for understanding how digital economies can drive ecological transition [25].

5. Conclusion

This study extends the analytical model of Zhou et al. (2024) on logistics service strategies for green agricultural e-commerce into a broader sustainability framework termed the Digital Green Supply System (DGSS). By integrating digital logistics optimization with sustainable agricultural value chains, the research highlights how e-commerce platforms can evolve from transactional intermediaries into strategic enablers of sustainability and rural development. The findings suggest that digital logistics integration, supported by real-time data analytics, route optimization, and environmental monitoring can simultaneously enhance profitability, reduce emissions, and foster social inclusivity.

At the conceptual level, the DGSS framework advances three major contributions. First, it demonstrates that economic efficiency and environmental performance are not mutually exclusive but can reinforce each other when mediated by digital intelligence. The same data infrastructures that optimize delivery time and cost can also minimize carbon intensity and waste, transforming logistics into a lever of sustainability. Second, it establishes logistics as the systemic core of sustainable agriculture, connecting farm-level production with market demand through a digitally coordinated and ecologically conscious network. Third, it introduces a self-adaptive mechanism where continuous feedback between logistics performance and sustainability indicators enables learning, correction, and innovation across the entire value chain.

From a policy perspective, the implications are both strategic and urgent. Governments and institutions should recognize e-commerce logistics as a public infrastructure for sustainability, not merely a private business function. Incentive schemes such as green logistics subsidies, carbon credits for platform-based emission reduction, and digital inclusion grants for rural producers can accelerate adoption. Policies should also encourage open data sharing between logistics platforms, agricultural agencies, and research institutions to enhance transparency, traceability, and accountability in the green transition.

Furthermore, investment in rural digital infrastructure including cold-chain systems, renewable-powered transport fleets, and smart warehousing is essential to expand the benefits of e-commerce integration beyond urban markets. Partnerships between local cooperatives and digital platforms can operationalize sustainability goals by co-managing logistics hubs, standardizing environmental reporting, and promoting circular packaging initiatives. In practice, the DGSS model provides a blueprint for developing eco-efficient, data-driven, and inclusive agricultural ecosystems. It calls for a paradigm shift from fragmented, carbon-intensive logistics toward integrated systems that combine digital precision with ecological responsibility. The long-term vision is to establish agricultural supply chains that are not only smart and fast but also green, resilient, and socially equitable.

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