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Conceptual Paper

Sustainable and Competitive? The Dual-Role of Information Systems in Green Supply Chain Operations

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Abstract. This is a conceptual theory-building paper that questions the notion of a "trade-off narrative" between sustainable supply chain management. It claims that advanced Information Systems (IS) play a crucial dual function in designing the co-construction of environmental and competitive value. The paper proposes a Dual-Role framework based on an abductive analysis of modern literature, mapping the synergistic impact pathways of these technologies. The framework proposes that the Internet of Things (IoT) allows data-driven closed-loop control, blockchain provides cryptographic trust, Artificial Intelligence (AI) offers predictive intelligence for systemic leanness, and cloud platforms offer orchestration and alignment. The framework results in a series of research propositions that can be tested and specify the likely conditions for this dual value creation. We argue that strategically located IS can transform sustainability from a constraint on operations to a parameter of the design for competitive advantage. This study offers a propositional theory for scholars to guide empirical research, as well as a principled rationale for managers to view digital investments as a foundation for planetary and business resilience.

Keywords: Sustainable Supply Chain Management (SSCM), Digital Transformation, Information Systems, Competitive Advantage, Theory-Building.

Introduction

Today's global supply chain has a double imperative of unique complexity. On the other hand, it should meet the conventional requirements in respect of cost-effectiveness, agility, and resilience for a competitive advantage in fluctuating markets. On the other side, it is under increasing pressure to reduce its significant environmental impact due to stringent regulations, investor pressure, and changing consumer demands for sustainable practices [1]. Operations management theory and practice frequently capture this duality as a fundamental trade-off, in which protecting the environment always comes at an economic cost, making managers into zero-sum thinkers between profit and planet [2]. However, the rapid pace of digital transformation in businesses is challenging this trade-off narrative.

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Information system (IS) technologies like the Internet of Things (IoT), blockchain, artificial intelligence (AI), and integrated cloud platforms are theorized as being strategic levers that can break down the classic trade-off [4]. This is a conceptual paper that argues that modern IS can serve as an important dual enabler for both demonstrable environmental sustainability and strong competitive advantage in supply chain operations.

The environmental need for this synergy is stark. The life cycle of a company is mostly determined by the supply chain, and more than 80% of the Greenhouse Gases (GHGs) emitted in many of the sectors producing goods for consumers are attributable to the supply chain, as well as a great deal of resource depletion and waste [5]. Meanwhile, the digital revolution has brought with it a series of technologies that drastically change the way material and information flows are seen, analyzed, and controlled. Academic literature reflects this evolution, with an increasing number of studies exploring how specific digital technologies facilitate green supply chain management. These studies discuss the use of IoT (Internet of Things) sensors for real-time energy monitoring, the value of blockchain in preserving the immutability of the circular economy flows, and the use of AI for optimizing logistics for reduced emissions [6].

Most researchers focus on how technology adoption affects either sustainability payoffs or overall operational performance. What's missing is an integrative framework that systematically and explicitly theorizes the causal mechanisms involved in a single IS investment that will support both the environmental and economic agendas. This gap, if not justified, might be an underestimation of the transformative power of IS, more as an architecture for value creation in a strategic sense [7]. The goal is to create and communicate a dual-role concept for advanced IS that explains how sustainability can be connected to business goals and therefore be considered an efficiency, innovation, and market differentiator, rather than a cost center.

The paper will take up three research questions to guide this inquiry. First, how to achieve both environmental and competitive performance in supply chains as a result of using advanced information systems. Second, how do IoT, blockchain, AI, and cloud platforms bring this twofold value in particular? Third, under what organizational and relational conditions are these dual-role effects most likely to occur?

1. Methods

This paper is intended as a conceptual paper – theory building. It is not a hypothesis-testing effort through the collection of new empirical data but an effort to summarize and suggest a new integrative approach that sheds light on a complex phenomenon [8][9]. The purpose of this paper is to develop a common argument that it is possible to explain how advanced IS can help reconcile the perceived tension between achieving environmental sustainability and competitive performance in the supply chain. In this regard, a three-phase iterative process of phase analysis was carried out, namely (1) Problematization and Domain Specification, (2) Iterative Abstraction and Framework Development, and (3) Proposition Formulation and Justification. The methodology used is organized, but not necessarily linear, and it has logical rigor and transparency in the development of a generalized theoretical model from such various empirical observations [10]. Peer-reviewed scholarly publications from information

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systems, supply chain management, operations management and sustainability literature are the key sources of information used in this analysis. These were found by conducting specific research on Scopus and Web of Science with keywords including "Internet of Things AND supply chain AND sustainability", "blockchain AND circular economy AND performance", "artificial intelligence AND green logistics", and "cloud platforms AND supply chain resilience". The initial search yielded approximately 220 publications after deduplication. Title and abstract screening were conducted to retain only those articles with English publications from 2015 to 2024 that: (1) addressed at least one of the four technologies under study, (2) discussed both an environmental or sustainability outcome and a competitive or operational outcome, and (3) were published in peer-reviewed journals. This process resulted in 68 full-text articles for detailed analysis. Each article was coded along three dimensions: the primary IS-enabler, the reported sustainability mechanism, and the corresponding competitive mechanism. Propositions P1-P4 were formulated through iterative pattern recognition across coded articles, where consistent relationships between an enabler and paired outcomes were abstracted into propositional statements and grounded in the natural resource-based view.

1.1. Phase 1: Problematization and Domain Specification

The point of departure of any conceptual investigation lies in the identification of the theory gap that attracts the interest of scholars [11]. The investigation started with engaging with two strong, but largely parallel, currents of literature in a critical fashion. The first stream is related to the role of digital technologies (Internet of Things, blockchain, and artificial intelligence) for sustainable practices in supply chain management [12]. The second stream analyzes the role of these same technologies for achieving traditional competitive goals such as cost, speed, and resilience [13].

This literature has been problematized through an iterative reading process, which identified a theoretical gap: both streams recognize IS capabilities, but few intersect to explain how a technological intervention can support both environmental and economic agendas. This decoupling becomes a mindset of management that is based on trade-offs and doesn't consider synergy. The domain was defined as the intersection of the advanced IS enablers and measurable environmental outcomes in supply chains (e.g., emission reduction, waste minimization) and core competitive outcomes (e.g., cost leadership, operational agility).

1.2. Phase 2: Iterative Abstraction and Framework Development

Given the domain, an iterative abstraction was made to build up the basic analytical structure. This phase included an intentional interaction with the literature, which is conducted in order to see patterns and relationships between the literature [14]. The analysis was of the abductive type, in which the researchers oscillate between the empirical, concrete findings and conceptualization [15]. The literature evidence was coded systematically in three dimensions: IS enabler (e.g., IoT, blockchain), main sustainability mechanism activated (e.g., real-time monitoring for efficiency), and the mechanism in the game (e.g., cost reduction from optimized resource use). It was noted via constant comparison that these mechanisms were not separate but often a single act with two consequences because they were data-driven. This repeated pattern led to the development of the concept of a dual-role enabler, which is an

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information system whose functionality yielded two parallel outcomes from the same data-driven action: an environmental and competitive benefit.

1.3. Phase 3: Proposition Formulation and Justification

The last stage was to make the descriptive approach a theoretical contribution by creating testable research propositions. The classification of a conceptual model, along with prediction and explanation, makes it scholarly useful [16], [17]. For each cell of the framework, it was asked what the underlying logic was connecting the IS enabler to this particular pair of outcomes. To articulate this logic, these observations needed to be grounded in already existing theoretical lenses, in particular the Natural Resource-Based View (NRBV) of the firm [18], which suggests that pollution prevention and product stewardship can provide a firm with a competitive advantage.

A set of foundational propositions was developed by combining the evidence mechanism from the literature with these theoretical anchors. In the next section of this paper, the fully developed dual-role framework is discussed, and the next four propositions are explicated using selected evidence from the literature, which is not intended to be proof; rather, it is only meant to provide illustrative justification for each of the theoretical claims.

2. Results

This is a conceptual study, and no statistical analyses or hypothesis testing with empirical data will be used. Rather, the results are presented as a theoretical framework and testable research propositions that are an outcome of the iterative abductive analysis described in the Methods section.

IS Enabler	***Exemplary SCM Application***	***Proposed Dual-Role Mechanism***	***Sustainability Impact (Green Role)***	***Competitiveness Impact (Business Role)***
IoT & Sensing Technology	*Real-Time monitoring of assets, fleets, and environmental conditions*	*Continuous sensor data enables dynamic optimization of physical processes, simultaneously minimizing inefficiency and resource intensity*	*Fuel & energy optimization*	*Lower operational cost; improved asset utilization and reliability*
Blockchain	*Provenance tracking for materials, components, and circular economy assets*	*Creates a shared tamper-proof record that transforms ethical/environmental claims into tradable, low-risk, verifiable assets*	*Ensures ethical sourcing, validates recycled content; enables circularity*	*Builds brand trust & premium positioning*
AI & Advanced Analytics	*Predictive demand forecasting, dynamic route optimization, and prescriptive maintenance*	*Advanced algorithms convert uncertainty into optimized probability, aligning economic and environmental efficiency by design*	*Minimizes overproduction & inventory waste*	*Reduces inventory holding costs*
Integrated Cloud Platforms	*Shared data hubs for collaborative logistics, carbon accounting, and enterprise planning*	*Provides a unified data infrastructure that breaks down silos, enabling coordinated, data-driven action across organizational boundaries*	*Enables Scope 3 emissions tracking & collaborative reduction plans*	*Enhances supply chain resilience & partner coordination*

Table 1. The Dual-Role Framework for IS in Sustainable and Competitive Supply Chains

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The general result of this study is the Dual-Role Framework, which is summarized in the following Table 1. The framework consists of four enablers of advanced information systems: IoT, blockchain, AI, and cloud platforms, and it provides the mechanisms by which each enabler provides value concurrently to both the environment and the competition. After the presentation of the framework, each enabler is analyzed in more detail and a research proposition is developed for each enabler.

The conceptual logic of the paper is visually synthesized below in Figure 1, which presents the Dual-Role Framework developed through the abductive analysis. The framework illustrates the theorized pathways through which each IS enabler generates concurrent environmental and competitive value, subject to the organizational and relational moderating conditions that shape these effects.

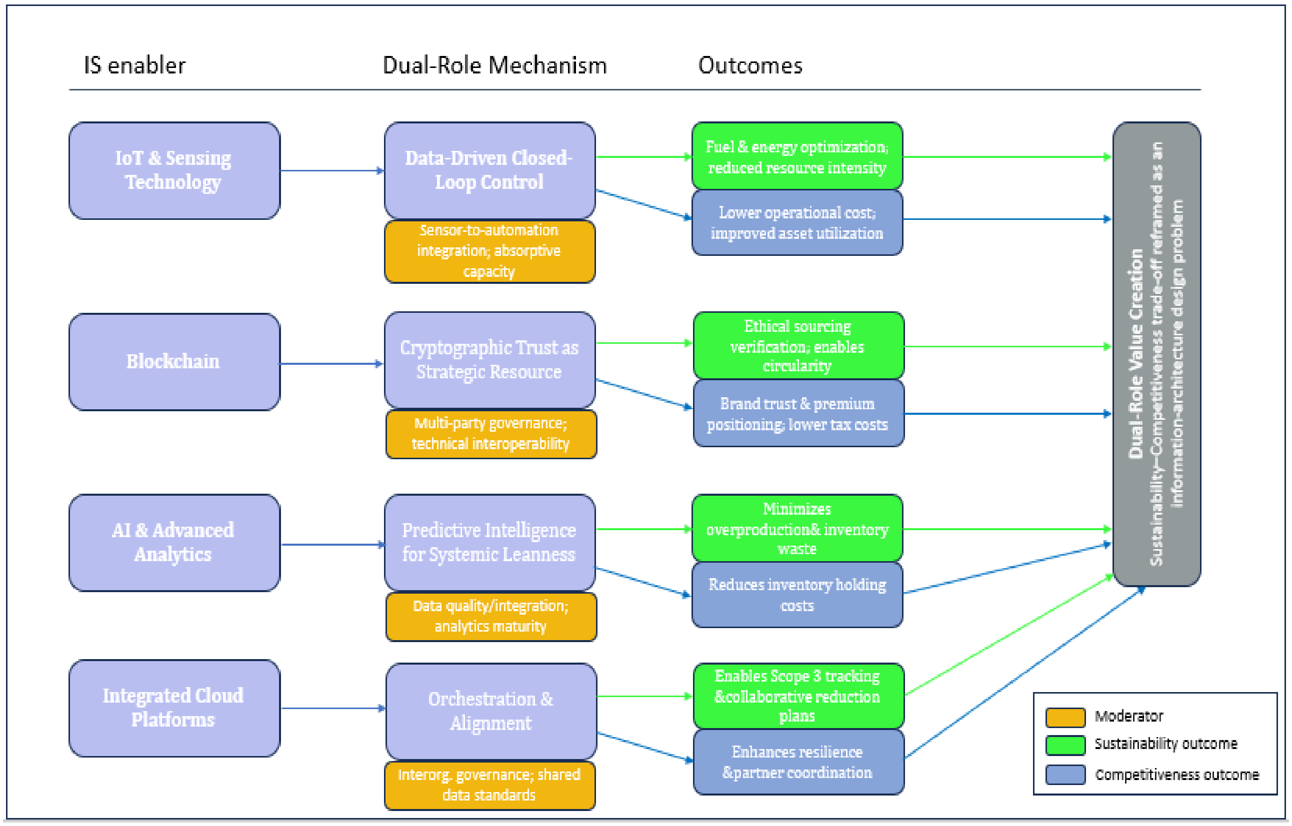

Figure 1. The Dual-Role Framework: Pathways from IS Enablers to Environmental and Competitive Outcomes

2.1. IoT and Sensing Technologies: The Mechanisms of Data-Driven Closed-Loop Control

The IoT enables a paradigm change from periodic sample-based management to closed-loop control of physical assets in the supply chain, based on data shown in Figure 1. This change is based on the dual-role thesis. The synergy mechanism of IoT is based on theories that rely on the fact that IoT acts as a distributed sensory nervous system and provides high-fidelity real-time information about the consumption of resources, status of assets, and environmental information [19]. This data stream could be incorporated into an analytic and execution system and facilitate a dynamic feedback loop for continuous optimization of operations [12]. The concept goes directly to the NRBV pollution prevention philosophy, which states that the best way to reduce pollution is to reduce the input of materials and

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energy, giving both environmental and cost benefits [18]. IoT brings this approach to life by providing instant visibility and actionability for inefficiencies. The competitive gain is not a standalone result but is based on the same data set. This situation exemplifies "resource complementarity," where data infrastructure for sustainability also supports economic performance.

The literature illustrates this closed-loop control in practice. IoT telematics can be used in logistics for dynamic route optimization through real-time data. Analyses of telematics data from commercial fleets have been conducted and prove that these types of dynamic routing and driver feedback systems can reduce fuel usage and associated CO2 emissions, proportional to the amount of system integration and data use [20]. Predictive energy management is done using IoT sensor networks in industrial environments. In another pioneering study of IoT applications in energy optimization in a manufacturing plant, it was shown that a sensor-based monitoring and control system can reduce energy consumption significantly, resulting in cost savings and improved process stability [21]. At the heart of the core mechanism are studies like these, which are good examples of the essence of the core mechanism: IoT-derived data closes the control loop; optimization of operations is equivalent to being interested in environmental performance.

But it isn't sufficient to just have sensors. Moderating factors of the proposed synergistic relationship are the degree of integration of the sensor data with automated systems for decision-making and the absorptive capacity of the organizations to understand and translate the data-driven knowledge into action. Proposition 2: The use of IoT-based sensory networks is positively related to improvements in environmental performance and operational cost performance. It is found that the level of integration of sensor data into automated, closed-loop control systems is a positive moderator in this relationship.

2.2. Blockchain: The Mechanism of Verifiable and Cryptographic Trust as a Strategic Resource

Blockchain technology brings a fundamental change in the way trust and provenance are built in complex supply chains, as shown in Figure 1. The key dual-role principle works by creating a decentralized, tamper-proof ledger that turns subjective statements of sustainability into objective and verifiable facts and truths among permissioned partners [22]. This technology is a direct response to two market failures: information asymmetry on the origin of products and illiquidity of environmental assets. This synergy is because the same cryptographic security that provides a record of ethical sourcing or carbon reduction also provides brand security, lowers transaction costs and enables new monetizable value to be created [23]. Basically, blockchain transforms transparency in the supply chain from a liability into an asset, linking economic motives for engaging in the chain with the common goal of a verifiable green supply chain.

There are clear examples in the literature of this trust-based mechanism. One of the main issues with the long and complex multi-tier supply chains is the ability to keep track of the history of the product, which is achieved by the inherent record-keeping properties of blockchain in ethical provenance tracking. The studies on food supply chains indicate that the blockchain structure can bring the traceability duration of a product to seconds and, as a result, limit the range of contamination, reduce the related food waste, and increase the trust level of consumers [24]. This demonstrates the twofold

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effect – food waste reduction and safeguarding of revenue and brand equity. Blockchain protocols can enable the circular economy by providing the creation of digital material passports to verify recycled content and components in complex recovery and remanufacturing cycles while maintaining data confidentiality. Furthermore, blockchain could also be employed to tokenize carbon credits and renewable energy certificates in environmental commodity markets, reducing fraud and administration processes [25]. This unlocks capital for sustainable investments and offers companies a more efficient and reliable way of achieving decarbonization goals.

However, like all network mechanisms, network adoption and network governance are needed to make this one effective. Proposition 2: Implementing a blockchain-based proof-of-provenance system positively impacts both environmental/social governance and market-based performance. The higher the multi-party governance and technical interoperability across the network, the more positive the relationship is.

2.3. AI and Advanced Analytics: The Mechanism of Predictive Intelligence for Systemic Leanness

AI and advanced analytics are a change of paradigm in supply chain management, changing over from reactive descriptive control to prescriptive optimization, see Figure 1. The dual-role mechanism, so-called predictive intelligence for systemic leanness, is at the core of this change. It involves the use of machine learning (ML) and advanced algorithms, such as modeling hypothetical and complex systems and translating uncertainty into optimized probability [26]. This synergy is simple: the best algorithmic model to minimize the cost of an efficient production sequence or delivery route is also the one that uses the least environmental resources. By increasing the efficiency through better information processing, there is no longer a trade-off between green and competitive results [27]; the purpose of AI is to identify the Pareto optimum on the efficiency front that fulfills both constraints.

The literature illustrates this systemic optimization mechanism in the areas of the supply chain. In demand and inventory management, ML models that consider various types of data streams have been proven to be effective and very accurate in forecasting [28]. In retail and FMCG, these AI-based forecasts contribute to less waste in inventory, leading to a lower embedded carbon footprint and improved service levels and working capital efficiency [29]. For logistics, systems for dynamic routing that optimize along multiple parameters can clearly reduce travel distance and fuel consumption with the help of AI. In general, an overview of the use of AI in transport is that these optimization algorithms can lead to significant fuel savings, which consequently result in emissions savings, to an increase in the efficiency of the transport network, and to a reduction of the costs of the operations [30]. A waste reduction example of this dual-role logic is pattern recognition using AI, which can identify inefficiencies. The research results show a 28.5% decrease in food waste, which resulted in a direct decrease in the cost of purchasing food when the intervention was automated with monitoring and analytics [31].

This potential is qualified by data quality and integration, as well as organizational capability in the ability to act on the algorithmic prescriptions. Proposition 3: Using AI and advanced analytics for supply chain planning and execution has a positive relationship with implementing environmental and

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operational performance simultaneously. This relationship is positively moderated by input data quality and integration, and the maturity of the organization's analytical capabilities.

2.4. Integrated Cloud Platforms: The Mechanism of Orchestration and Alignment

Cloud computing platforms are integrated systems that are critical to the infrastructure of a modern, connected supply chain, as illustrated in Figure 1. They have a dual function of orchestration and alignment; they present a single and scalable data platform that eliminates informational silos between functions and companies and enables aligned and synchronized action towards the same goals [32]. This integration is the fundamental mechanism, and cloud platforms do not sense, verify, or optimize directly, but they support the scalable integration of IoT, blockchain, and AI technologies [13]. The synergy is evident: the same data infrastructure that enables a network of partners to measure and reduce their collective carbon footprint also enhances real-time visibility and coordination of actions, which in turn improves resilience, increases mitigation efforts, and supports innovation [33]. The supply network is therefore considered a network of bilateral transactions as well as an integrated and flexible network, where environmental and economic goals can be realized through coherent data flows.

Evidence from implementation studies supports the orchestrating role. Cloud-based supply chain control towers exemplify this mechanism by aggregating data from various sources and providing comprehensive visibility throughout the supply chain. Literature indicates that they are beneficial for reducing the bullwhip effect and inventory level, and these, in turn, reduce overproduction waste and emissions and improve on-time delivery and working capital efficiency [13]. In carbon accounting, there are niche cloud providers trying to address the incredible challenge of Scope 3 emissions [34]. These platforms standardize data collection and calculation processes throughout the value chain, transforming it from an estimate-based process to a transparent and collaborative process. This capability is crucial for meeting the increasingly stringent disclosure requirements, and it facilitates pinpointing areas for decarbonization efforts, which can identify previously unknown synergistic opportunities between partners and compliance activities and mitigate risks and costs while providing strategic business insights [35]. Cloud platforms also offer digital ecosystems to enable the circular economy, for example, product lifecycle management (PLM) systems to manage components for remanufacturing. These systems can foster the circular flows to save resources and generate new income streams through reconditioned products and services [36].

Interorganizational governance and common data standards are a critical part of the effectiveness of this mechanism. Proposition 4: Using an integrated cloud platform is positively correlated with both better environmental governance and better network-based competitiveness. The relationship is positively moderated by the presence of strong interorganizational governance structures and shared data standards.

3. Discussion

This chapter provides an interpretation of the results obtained in the previous section and discusses the broader implications of these results. The discussion follows the three research questions, and

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theoretical implications, practical implications, limitations, and an agenda for future research are presented.

3.1. Answering the Research Questions

Research Question 1: How do advanced Information Systems enable concurrent environmental and competitive performance in supply chains?

These results show that advanced IS is able to operate as a data-to-action pipeline: the sequence through which raw data is collected, processed, analyzed, and translated into operational decisions that yield measurable outcomes. Each technology produces optimized physical or transactional results from raw data. IoT enables closed-loop control of energy and materials based on sensor data. Provenance data is a way to achieve verifiable trust and minimize risk through blockchain. AI transforms historical and real-time data into predictive intelligence while reducing waste and costs at the same time. Cloud platforms align the fragmentation of data across partners and integrate it in an orchestrated way in the system. The same data flow in each case generates two parallel outputs, an environmental benefit and a competitive benefit. The zero-sum constraint of the sustainability-competitiveness relationship has been reframed as a design problem of information architecture.

Research Question 2: What are the distinct mechanisms through which IoT, blockchain, AI, and cloud platforms generate this dual value?

Four different, yet interrelated, mechanisms were found in the analysis. The mechanism is data-driven closed-loop control: Continuous sensing allows for real-time optimization of resource-intensive processes for IoT. The mechanism for blockchain is cryptographic trust as a strategic resource—immutable records that make subjective sustainability claims verifiable and tradable assets. In the case of AI, it uses advanced algorithms to predict and find the best ways to be efficient while considering both environmental and economic limits. Cloud platforms and their orchestration and alignment: the cloud has a unified data infrastructure that eliminates data silos and allows you to act across organizations. These mechanisms are not mutually exclusive but operate together and are intertwined in real terms, supported by cloud platforms for the universal integration of IoT, blockchain, and AI.

Research Question 3: Under what organizational and relational conditions are these dual-role effects most likely to occur?

These results indicate several important moderators. Absorptive capacity is a condition for the realization of potential dual value at the organizational level. Inter-organizational governance and shared data standards are relational and crucial for the ability of such platforms as blockchain and cloud to operate across firm boundaries. Technically, the accuracy and consistency of data quality and integration are critical factors that impact the reliability and actionability of AI outputs. The framework thereby assumes that the dual-role effect is contingent and not automatic. However, technology alone is not enough; complementary capabilities and governance structures are needed.

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3.2. Theoretical Synthesis and Contribution

The Dual-Role Framework makes three interrelated contributions to the literature on sustainability supply chains. It offers a mechanistic merger of the natural resource-based view and present-day digital supply chain theory for the first time. The NRBV has long been interested in the potential of pollution prevention and product stewardship as sources of competitive advantage, but has been very quiet about how to create this synergy operationally in a complex, networked environment. This research framework explains the exact digital pathways to operationalize NRBV strategies and, hence, an up-to-date theory for the digital age.

Second, the framework is not a descriptive taxonomy, but rather a contingent, propositional theory. A lot of the literature available lists technologies and what they can do. This paper, on the other hand, proposes a testable model consisting of four propositions setting forth predictive relationships and key moderators. This moves the research discussion away from describing what technologies are available to critically analyzing when they add dual value [17].

Third, the framework helps alleviate the ongoing disconnect between the green IS and digital SCM literature. Much of the work on environmental sustainability and on operational performance has been carried out independently. This paper offers a unified perspective on the data as the common resource that drives both results. The main theoretical principle is that the conflict between the planet and profit is not an axiom of functioning but rather is a symptom of informational constraint. However, the constraint is resolved when information flows are suitably designed.

3.3. Practical and Managerial Implications

The Dual-Role Framework changes the business case for digital investments. It claims that investments in IoT, blockchain, AI, and cloud platforms should be driven by the ability of these platforms to deliver dual value—both cost reduction and reduction of environmental footprint. This framework gives a reason to get funding and technology projects in line with corporate sustainability projects.

The framework also necessitates a paradigm shift in technology management, transitioning from technology procurement to ecosystem orchestration. The challenge to achieve the dual-role potential is to extend beyond integrating internally and to negotiate data-sharing arrangements, incentives, and co-governance with the organization's partners. Finally, the goal of deeper, transformative sustainability may not be measurable efficiency gains; it takes deliberate strategic commitment. The strategic mandate is to create incentive systems and goals that reward incremental efficiencies and systemic change towards circular and regenerative business.

3.4. Boundary Conditions and Potential Trade-Offs

The Dual-Role Framework reflects synergy, but the promise of digital synergy must be weighed against the practical, environmental, and governance constraints that accompany these technologies. The digital infrastructure itself has an environmental footprint; it all demands substantial energy, and it therefore consumes significant electricity [37]. Furthermore, high implementation costs restrict small and medium-sized enterprises from adopting these technologies. This leads to potentially widening

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competitive gaps between resource-rich corporations and smaller suppliers, creating a digital divide in the capacity to pursue green operations [38]. Furthermore, data centralization introduces governance vulnerability, including privacy breaches, cybersecurity threats, and vendor lock-in, while the immutability of blockchain records can conflict with data privacy regulations. These consequences do not invalidate the framework; rather, they define its boundaries. The proposed dual-role effects are most likely to materialize when organizations possess the financial and technical capacity to deploy these systems, the governance structures to manage data risks, and the strategic discipline to align algorithmic optimization with long-term sustainability goals.

3.5. Limitations and Future Research Agenda

This study is conceptual in nature, with studied choices that define its scope and accompanying limitations. First of all, the framework and its propositions are logically derived but have not yet been tested on the empirical level. Second, the analysis highlights the environmental component of sustainability, recognizing it but not fully incorporating it, and has a different set of stakeholder dynamics and measurement issues. Thirdly, the model is based on the premise of a certain level of technological and financial literacy, which may not be the case for small and medium enterprises or scenarios with high digital divides. These are not limitations but clarifications that determine the starting point of the theory.

Future work is needed to go from a proposition to a validated theory. Quantitative studies are required for statistically examining the proposed relationships in propositions 1-4 and the moderating effects of absorptive capacity and governance maturity. Further studies could also explore the organizational situation and inter-firm dynamics that affect the possibilities or limitations of the dual-role mechanisms. Finally, lifecycle assessment research is needed to evaluate the net environmental impact of green IS deployments, accounting for the energy consumption and e-waste of the digital infrastructure itself.

Conclusions

The main aim of this conceptual paper was to dispute a long-held assumption in the field of supply chain management that environmental sustainability and economic competitiveness are an inherent contradiction. The dual-role framework suggests that this trade-off is not one of the laws of operations, but rather a symptom of informationally constrained operations. Well-designed information systems, when used appropriately, can transform information into a tool that enhances both ecological and economic performance. The three major conclusions of this work are the following: First, the value creation mechanisms of the dual roles are identifiable: namely, IoT provides closed-loop control, blockchain ensures cryptographic trust, AI provides predictive intelligence, and cloud platforms offer orchestration. Second, these mechanisms are subject to conditions, not automatic. They are effective when there is high absorptive capacity in the organization, effective inter-firm governance, and high-quality data. Third, it considers sustainability to be a design parameter rather than a compliance issue for competitive operations.

These conclusions have two important implications for the field. The framework for scholars is a propositional, testable theory that takes the discussion beyond technology catalogs to causal

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explanation. It provides a principled investment argument for digital, with returns counted in both currency and carbon. But with this work come many more questions than answers. What is the role of these mechanisms in small and medium-sized enterprises without the resources of large companies? How does the energy use and e-waste from the digital infrastructure affect the environment, or even the opposite? What are some ways for organizations to create an algorithmically efficient and transformatively sustainable system without compromising either? Here are some questions for future investigation. Ultimately, the most successful and useful supply chains will be those that do not have to choose between profit and environmental sustainability; instead, they will learn to optimize both by leveraging the flow of data intelligence.

Author Contributions

Conceptualization: Issa Zayed Hattar; methodology: Issa Zayed Hattar; formal analysis: Issa Zayed Hattar; resources: Issa Zayed Hattar; data curation: Issa Zayed Hattar; writing—original draft: Issa Zayed Hattar; writing—review and editing: Timea Gal; supervision: Timea Gal.

All authors have read and approved the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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References

[1] Z. A. Saqib and Q. Zhang, “Impact of sustainable practices on sustainable performance: The moderating role of supply chain visibility,” *Journal of Manufacturing Technology Management*, vol. 32, no. 7, pp. 1421–1443, 2021, doi: 10.1108/JMTM-10-2020-0403

[2] C. J. Corbett and R. D. Klassen, “Extending the horizons: Environmental excellence as key to improving operations,” *Journal of Manufacturing & Service Operations Management*, vol. 8, no. 1, pp. 5–22, 2006, doi: 10.1287/msom.1060.0095.

[3] R. Gabryelczyk, “Has COVID-19 accelerated digital transformation? Initial lessons learned for public administrations,” *Information Systems Management*, vol. 37, no. 4, pp. 303–309, 2020, doi: 10.1080/10580530.2020.1820633

DOI: 10.21791/IJEMS.2026.10

[4] M. Pournader, H. Ghaderi, A. Hassanzadegan, and B. Fahimnia, "Artificial intelligence applications in supply chain management," *International Journal of Production Economics*, vol. 241, paper 108250, 2021, doi: 10.1016/j.ijpe.2021.108250

[5] F. V. Bekun, A. A. Alola, and S. A. Sarkodie, "Toward a sustainable environment: Nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries," *Science of the Total Environment*, vol. 657, pp. 1023–1029, 2019, doi: 10.1016/j.scitotenv.2018.12.104

[6] M. Ben-Daya, E. Hassini, Z. Bahroun, and B. H. Banimfreg, "The role of internet of things in food supply chain quality management: A review," *Quality Management Journal*, vol. 28, no. 1, pp. 17–40, 2020, doi: 10.1080/10686967.2020.1838978

[7] Bharadwaj, O. A. El Sawy, P. A. Pavlou, and N. Venkatraman, "Digital business strategy: Toward a next generation of insights," *MIS Quarterly*, vol. 37, no. 2, pp. 471–482, 2013, doi: 10.25300/MISQ/2013/37:2.3

[8] L. L. Gilson and C. B. Goldberg, "Editors' comment: So, what is a conceptual paper?," *Group & Organization Management*, vol. 40, no. 2, pp. 127–130, 2015, doi: 10.1177/1059601115576425

[9] E. Jaakkola, "Designing conceptual articles: Four approaches," *AMS Review*, vol. 10, no. 1, pp. 18–26, 2020, doi: 10.1007/s13162-020-00161-0

[10] J. Cornelissen, "Editor's comments: Developing propositions, a process model, or a typology? Addressing the challenges of writing theory without a boilerplate," *Academy of Management Review*, vol. 42, no. 1, pp. 1–9, 2017, doi: 10.5465/amr.2016.0196

[11] M. Alvesson and J. Sandberg, "Generating research questions through problematization," *Academy of Management Review*, vol. 36, no. 2, pp. 247–271, 2011, doi: 10.5465/amr.2009.0188

[12] M. Ben-Daya, E. Hassini, and Z. Bahroun, "Internet of things and supply chain management: A literature review," *International Journal of Production Research*, vol. 57, no. 15–16, pp. 4719–4742, 2019, doi: 10.1080/00207543.2017.1402140

[13] D. Ivanov, A. Dolgui, and B. Sokolov, "Cloud supply chain: Integrating Industry 4.0 and digital platforms in the 'Supply Chain-as-a-Service'," *Transportation Research Part E: Logistics and Transportation Review*, vol. 160, paper 102676, 2022, doi: 10.1016/j.tre.2022.102676

[14] B. M. Lindgren, B. Lundman, and U. H. Graneheim, "Abstraction and interpretation during the qualitative content analysis process," *International Journal of Nursing Studies*, vol. 108, paper 103632, 2020, doi: 10.1016/j.ijnurstu.2020.103632

[15] Dubois and L. E. Gadde, "Systematic combining: An abductive approach to case research," *Journal of Business Research*, vol. 55, no. 7, pp. 553–560, 2002, doi: 10.1016/S0148-2963(00)00195-8

[16] M. Naeem, W. Ozuem, K. Howell, and S. Ranfagni, "A step-by-step process of thematic analysis to develop a conceptual model in qualitative research," *International Journal of Qualitative Methods*, vol. 22, paper 16094069231205789, 2023, doi: 10.1177/16094069231205789

[17] D. A. Whetten, "What constitutes a theoretical contribution?," *Academy of Management Review*, vol. 14, no. 4, pp. 490–495, 1989, doi: 10.5465/amr.1989.4308371

[18] S. L. Hart, "A natural-resource-based view of the firm," *Academy of Management Review*, vol. 20, no. 4, pp. 986–1014, 1995, doi: 10.5465/amr.1995.9512280033

[19] K. Nayal, S. Kumar, R. D. Raut, M. M. Queiroz, P. Priyadarshinee, and B. E. Narkhede, "Supply chain firm performance in circular economy and digital era to achieve sustainable development goals," *Business Strategy and the Environment*, vol. 31, no. 3, pp. 1058–1073, 2022, doi: 10.1002/bse.2935

[20] D. Bechtsis, N. Tsolakis, E. Iakovou, and D. Vlachos, "Data-driven secure, resilient and sustainable supply chains: Gaps, opportunities, and a new generalised data sharing and data monetisation framework," *International Journal of Production Research*, vol. 60, no. 14, pp. 4397–4417, 2022, doi: 10.1080/00207543.2021.1957506

[21] M. Tu, M. K. Lim, and M. F. Yang, "IoT-based production logistics and supply chain system–Part 2: IoT-based cyber-physical system: A framework and evaluation," *Industrial Management & Data Systems*, vol. 118, no. 1, pp. 96–125, 2018, doi: 10.1108/IMDS-11-2016-0504

[22] Parmentola, A. Petrillo, I. Tutore, and F. De Felice, "Is blockchain able to enhance environmental sustainability? A systematic review and research agenda from the perspective of Sustainable Development Goals (SDGs)," *Business Strategy and the Environment*, vol. 31, no. 1, pp. 194–217, 2022, doi: 10.1002/bse.2882

[23] M. Nofer, P. Gomber, O. Hinz, and D. Schiereck, "Blockchain," *Business & Information Systems Engineering*, vol. 59, no. 3, pp. 183–187, 2017, doi: 10.1007/s12599-017-0467-3

[24] N. Kshetri, "Blockchain and sustainable supply chain management in developing countries," *International Journal of Information Management*, vol. 60, paper102376, 2021, doi: 10.1016/j.ijinfomgt.2021.102376

[25] S. K. Kim and J. H. Huh, "Blockchain of carbon trading for UN sustainable development goals," *Sustainability*, vol. 12, no. 10, paper 4021, 2020, doi: 10.3390/su12104021

[26] P. K. Singh, "Digital transformation in supply chain management: Artificial Intelligence (AI) and Machine Learning (ML) as catalysts for value creation," *International Journal of Supply Chain Management*, vol. 12, no. 6, pp. 57–63, 2023, doi: 10.59160/ijscm.v12i6.6216

[27] G. Baryannis, S. Validi, S. Dani, and G. Antoniou, "Supply chain risk management and artificial intelligence: State of the art and future research directions," *International Journal of Production Research*, vol. 57, no. 7, pp. 2179–2202, 2019, doi: 10.1080/00207543.2018.1530476

[28] F. Petropoulos, D. Apiletti, V. Assimakopoulos, M. Z. Babai, D. K. Barrow, S. B. Taieb, *et al*., "Forecasting: Theory and practice," *International Journal of Forecasting*, vol. 38, no. 3, pp. 705–871, 2022, doi: 10.1016/j.ijforecast.2021.11.001

[29] Bueno, M. Godinho Filho, and A. G. Frank, "Smart production planning and control in the Industry 4.0 context: A systematic literature review," *Computers & Industrial Engineering*, vol. 149, paper 106774, 2020, doi: 10.1016/j.cie.2020.106774

[30] R. Abduljabbar, H. Dia, S. Liyanage, and S. A. Bagloee, "Applications of artificial intelligence in transport: An overview," *Sustainability*, vol. 11, no. 1, paper 189, 2019, doi: 10.3390/su11010189

DOI: 10.21791/IJEMS.2026.10

[31] S. Jagtap, C. Bhatt, J. Thik, and S. Rahimifard, "Monitoring potato waste in food manufacturing using image processing and internet of things approach," *Sustainability*, vol. 11, no. 11, paper 3173, 2019, doi: 10.3390/su11113173

[32] S. Marston, Z. Li, S. Bandyopadhyay, J. Zhang, and A. Ghalsasi, "Cloud computing—The business perspective," *Decision Support Systems*, vol. 51, no. 1, pp. 176–189, 2011, doi: 10.1016/j.dss.2010.12.006

[33] G. Büyüközkan and F. Göçer, "Digital supply chain: Literature review and a proposed framework for future research," *Computers in Industry*, vol. 97, pp. 157–177, 2018, doi: 10.1016/j.compind.2018.02.010

[34] M. Hettler and L. Graf-Vlachy, "Corporate scope 3 carbon emission reporting as an enabler of supply chain decarbonization: A systematic review and comprehensive research agenda," *Business Strategy and the Environment*, vol. 33, no. 2, pp. 263–282, 2024, doi: 10.1002/bse.3486

[35] S. A. R. Khan, A. Z. Piprani, and Z. Yu, "Digital technology and circular economy practices: Future of supply chains," *Operations Management Research*, vol. 15, no. 3, pp. 676–688, 2022, doi: 10.1007/s12063-021-00247-3

[36] N. K. Dev, R. Shankar, and F. H. Qaiser, "Industry 4.0 and circular economy: Operational excellence for sustainable reverse supply chain performance," *Resources, Conservation and Recycling*, vol. 153, paper 104583, 2020, doi: 10.1016/j.resconrec.2019.104583

[37] J. C. T. Bieser and L. M. Hilty, "Assessing indirect environmental effects of information and communication technology (ICT): A systematic literature review," *Sustainability*, vol. 10, no. 8, paper 2662, 2018, doi: 10.3390/su10082662

[38] J. Álvarez Jaramillo, J. W. Zartha Sossa, and G. L. Orozco Mendoza, "Barriers to sustainability for small and medium enterprises in the framework of sustainable development—Literature review," *Business Strategy and the Environment*, vol. 28, no. 4, pp. 512–524, 2019, doi: 10.1002/bse.2261