The OSCAR PUBLISHING Services
American Journal of Applied Science and Technology

VOLUME Vol.05 Issue 12 2025
PAGE NO. 37-42

A Framework for Transformative Pharmaceutical Supply Chains: Integrating Sustainability, Resilience, Ethics, and Technology

Dr. Mariana Kovács
Global Institute for Supply Chain Research, University of Copenhagen, Denmark

Received: 22 November 2025; **Accepted:** 02 December 2025; **Published:** 09 December 2025

Abstract: This article develops an integrated, publication-ready theoretical and practical framework for sustainable pharmaceutical supply chain management that fuses environmental, social, and economic imperatives with emerging technologies and collaborative governance. Building on prior frameworks of sustainable supply chain management (Carter & Rogers, 2008; Closs, Speier & Meacham, 2011), supplier selection and triple bottom line evaluation (Ahi & Searcy, 2015; Govindan, Khodaverdi & Jafarian, 2013), and domain-specific studies in pharmaceuticals and healthcare logistics (Ding, 2018; Chaudhuri, 2015; Chen, Li & Wang, 2020), the article articulates an end-to-end model that emphasizes circularity, digital transparency, stakeholder co-creation, and public-health-aligned profit mechanisms (Dahan et al., 2010; Ding, Wang & Zheng, 2018). The paper synthesizes evidence on technological enablers — blockchain, big data analytics, Industry 4.0 advances — and social governance instruments to propose a coherent approach for measuring, implementing, and scaling sustainable practices across the pharmaceutical supply chain (Cole, Stevenson & Aitken, 2019; Barbosa et al., 2018; Ding, 2018). Methodologically, the work adopts a rigorous conceptual synthesis, comparative literature analysis, and construct-level triangulation of sustainability measurement instruments (Das, 2017; Shou et al., 2019). Results are presented as descriptive analyses and translatable managerial guidelines, showing how supplier evaluation, collaborative profit-allocation mechanisms, and digital tracking reduce waste and improve public health outcomes while maintaining commercial viability (Ding, Wang & Zheng, 2018; Chowdhury, 2025). The discussion interprets limitations, including measurement heterogeneity and governance complexity, and sets an agenda for empirical testing, simulation modeling, and policy experimentation. The conclusion offers concrete priorities for practitioners and policymakers to accelerate the transition to sustainable pharmaceutical supply chains that balance the triple bottom line and public-health imperatives.

Keywords
Sustainable supply chain; pharmaceutical logistics; circular economy; blockchain; triple bottom line; collaborative governance; Industry 4.0

INTRODUCTION

The pharmaceutical supply chain sits at the nexus of public health, commercial incentives, technical complexity, and global environmental pressures. It is simultaneously a vector for life-saving products and a contributor to resource consumption, waste generation, and social inequalities when mismanaged (Ding, 2018; Chen, Li & Wang, 2020). Traditional supply chain frameworks often prioritize cost, availability, and lead time, but contemporary crises — from pandemic-driven demand shocks to increased regulatory scrutiny and environmental concerns — demand a reorientation toward sustainability in its fullest sense: environmental stewardship, social responsibility, and long-term economic viability (Carter & Rogers, 2008; Closs, Speier & Meacham, 2011).

The literature on sustainable supply chain management furnishes foundational concepts and measurement tools that are applicable to pharmaceuticals but lacks a fully integrated model tailored for the sector's unique obligations to public health, safety, and regulatory oversight (Das, 2017; Ding, 2018). Recent advances in digital technologies

— blockchain for provenance and transparency, big data analytics for demand prediction, and Industry 4.0 practices for process efficiency — offer unprecedented opportunities to reconcile sustainability with the operational rigor required by pharmaceutical distribution (Cole, Stevenson & Aitken, 2019; Barbosa et al., 2018). At the same time, social innovations in stakeholder collaboration (e.g., corporate–NGO partnerships) and new profit-allocation mechanisms that explicitly consider public health outcomes create the institutional scaffolding needed for sustainable transitions (Dahan et al., 2010; Ding, Wang & Zheng, 2018).

Problem statement. Despite the conceptual progress, pharmaceutical supply chains still lack a validated, cohesive framework that brings together: (a) rigorous sustainability measurement across the triple bottom line adaptable to pharmaceutical product characteristics (Ahi & Searcy, 2015; Govindan, Khodaverdi & Jafarian, 2013); (b) technology-enabled transparency and circularity mechanisms that reduce waste without compromising safety or efficacy (Cole, Stevenson & Aitken, 2019; Ciulli, Kolk & Boe-Lillegraven, 2020); and (c) collaborative governance structures that align commercial incentives with public health outcomes (Dahan et al., 2010; Ding, Wang & Zheng, 2018). This gap frustrates the ability of researchers and practitioners to systematically design interventions that are both ethical and operationally feasible.

Literature gap. Existing studies tend to either (1) develop sector-agnostic sustainability theories without operational specificity for pharmaceuticals (Carter & Rogers, 2008; Closs et al., 2011), (2) analyze technological enablers without integrating measurement and governance (Cole et al., 2019; Barbosa et al., 2018), or (3) present isolated case studies that do not scale to system-level prescriptions (Chaudhuri, 2015; Chen et al., 2020). Moreover, many supplier selection and sustainability-evaluation models address manufacturing or retail contexts but do not sufficiently capture regulatory stringency, cold-chain sensitivity, and recall risk that characterize pharmaceutical flows (Das, 2017; Padhi, Pati & Rajeev, 2018). A fully integrated framework that addresses these lacunae is absent.

Contribution. This article constructs a comprehensive conceptual and practical model for sustainable pharmaceutical supply chains that unites triple-bottom-line measurement, digital transparency (including blockchain-enabled provenance), circular economy principles, and collaborative profit and governance mechanisms aligned with public health. It synthesizes extant constructs into operationalizable practices and a measurement architecture ready for empirical validation. The model is intended to serve academia, industry managers, regulators, and non-governmental partners seeking evidence-based pathways to reduce waste, increase equity, and sustain firm performance simultaneously.

METHODOLOGY

This research follows a deliberate, multi-step conceptual methodology designed to create a publication-quality integrative framework grounded in the supplied references. Given the nature of the task — integrating theory, managerial practice, and technological enablers — a mixed-methods conceptual approach is most appropriate. The methodology consists of systematic literature synthesis, construct triangulation, conceptual model building, and evaluation criteria formulation.

Systematic literature synthesis. The first step involved a comprehensive synthesis of the provided literature on sustainable supply chain management, pharmaceutical-specific logistics, supplier selection methods, digital technologies, collaborative governance, and circular economy approaches (Carter & Rogers, 2008; Closs et al., 2011; Ding, 2018; Cole et al., 2019; Dahan et al., 2010). The synthesis prioritized identifying recurring constructs (e.g., transparency, supplier social performance, lifecycle assessment) and mapping relationships to pharmaceutical-specific risks (e.g., cold-chain failure, counterfeiting, regulatory non-compliance) as discussed across the references (Das, 2017; Shou et al., 2019; Chen et al., 2020).

Construct triangulation and operational definition. For each major concept — environmental performance, social performance, economic viability, traceability, circularity, governance — the literature was examined to extract measurement items, operational definitions, and suggested evaluative approaches (Ahi & Searcy, 2015; Govindan et al., 2013; Mani & Gunasekaran, 2018). Where sector-specific measures existed (e.g., quality regulation effects on pharmaceutical supply chains), these were adapted and extended into operationalizable constructs (Chen, Li & Wang, 2020).

Conceptual model building. Building on Carter and Rogers' sustainable supply chain framework and incorporating supplier selection and collaborative profit-allocation literature, a unified model was developed. It positions technological enablers (blockchain, big data analytics, Industry 4.0 practices) as mediating mechanisms that enhance measurement fidelity and enable circular practices (Cole et al., 2019; Barbosa et al., 2018). Simultaneously, governance modalities (corporate–NGO collaboration, public–private partnerships) are

treated as moderators that influence the adoption and effectiveness of sustainable interventions (Dahan et al., 2010; Ding et al., 2018).

Evaluation criteria formulation. To make the model actionable, the methodology proposes specific evaluation criteria and suggested metrics drawn from the literature: triple-bottom-line indicators and supplier evaluation processes, social sustainability decision-support approaches, and fuzzy multi-criteria assessment examples (Govindan et al., 2013; Bai et al., 2019; Sarkis & Dhavale, 2015). These criteria are descriptive, non-mathematical, and intended for later empirical testing.

Validity and limitations. The methodology is conceptual and synthetic by design — it does not report empirical fieldwork in this manuscript. Its validity rests on the thoroughness of the synthesis and the coherence of construct adaptation from authoritative references. Limitations include potential selection bias (reliance on provided references) and the absence of new primary data, which the discussion addresses by recommending next-step empirical and simulation work (Ding, 2018; Ciulli et al., 2020).

RESULTS

The results are presented as an integrated framework, detailed construct descriptions, and managerial guidance for implementation. The findings synthesize how specific practices and technologies converge to produce sustainable, resilient pharmaceutical supply chains.

Integrated framework: overview. The framework comprises four interconnected pillars: Governance and Collaboration; Measurement and Supplier Selection; Technological Enablers and Operationalization; Circularity and Waste Reduction. Each pillar draws on multiple references and includes subcomponents that operationalize theory into practice.

Governance and Collaboration. Collaborative modalities — including corporate–NGO partnerships, public–private arrangements, and multi-stakeholder platforms — are central to aligning firm incentives with public-health outcomes (Dahan et al., 2010). The literature demonstrates that co-creation of business models with NGOs and regulators can reconfigure profit allocation to reward public-health-protecting behaviors, such as investing in temperature-monitoring systems or subsidizing recalls, thereby internalizing externalities (Dahan et al., 2010; Ding, Wang & Zheng, 2018). These arrangements provide legitimacy, risk-sharing, and access to specialized social capabilities that firms often lack (Dahan et al., 2010).

Measurement and supplier selection. Sustainable supplier evaluation should integrate environmental, social, and economic criteria tailored to pharmaceutical specifics: cold-chain capability, regulatory compliance history, labor and human-rights indicators, lifecycle environmental impacts (Ahi & Searcy, 2015; Govindan et al., 2013; Das, 2017). Methods from fuzzy multi-criteria decision-making and Bayesian frameworks provide pathways to handle uncertainty and conflicting criteria in supplier selection (Govindan et al., 2013; Sarkis & Dhavale, 2015). The result is a supplier scorecard that privileges not only cost and quality but also social and environmental stewardship, especially in remanufacturing, reuse, and safe disposal streams (Cesur et al., 2020; Ciulli et al., 2020).

Technological enablers and operationalization. Blockchain and big data are not panaceas but valuable mediators for transparency, provenance, and traceability (Cole et al., 2019; Barbosa et al., 2018). Blockchain provides immutable provenance records that reduce counterfeiting risk and increase visibility into cold-chain events, enabling faster corrective actions and better recall management (Cole et al., 2019; Chowdhury, 2025). Big data analytics improve demand forecasting and inventory optimization, reducing waste from expiry and overstocking — a key environmental and economic problem for pharmaceuticals (Barbosa et al., 2018; Chen et al., 2020). Industry 4.0 practices, such as sensor-based monitoring and automated quality checks, increase process reliability and create richer datasets for sustainability metrics (Ding, 2018).

Circularity and waste reduction. Circularity in pharmaceuticals is complicated by safety, contamination, and regulatory constraints, yet opportunities exist in packaging recovery, take-back programs, and process remanufacturing where clinically safe (Ciulli et al., 2020; Cesur et al., 2020). Digital platforms and circularity brokers can coordinate waste recovery, reduce resource extraction, and generate new value streams through material reclamation and closed-loop packaging systems (Ciulli et al., 2020). Combining technological tracking with socially embedded collection mechanisms enables viable circular flows while preserving patient safety.

Construct integration and causal propositions. The results synthesize into several core propositions grounded in the literature: (1) Blockchain-enabled provenance increases supplier accountability and reduces counterfeit risk, which, combined with stricter supplier selection, improves social and environmental outcomes (Cole et al., 2019; Chowdhury, 2025). (2) Big data analytics reduce

inventory waste and expired products by improving demand accuracy and inventory replenishment decisions (Barbosa et al., 2018; Chen et al., 2020). (3) Corporate–NGO and public–private collaborations enable profit-allocation mechanisms that internalize public-health benefits, increasing firm willingness to invest in sustainability measures that may not show short-term returns (Dahan et al., 2010; Ding et al., 2018). (4) Circularity brokers and digital platforms enable material recovery that both reduces environmental footprint and provides cost offsets, contingent on rigorous safety protocols (Ciulli et al., 2020; Cesur et al., 2020).

Managerial guidance. From these propositions, practical steps emerge: adopt supplier evaluation scorecards including cold-chain and social indicators (Das, 2017); pilot blockchain for high-value or high-risk product lines to validate provenance benefits (Cole et al., 2019); invest in sensor-enabled monitoring and predictive analytics for inventory and temperature control (Ding, 2018; Barbosa et al., 2018); and form strategic collaborations with NGOs and public bodies to share risks and co-invest in community-level collection and disposal programs (Dahan et al., 2010; Ding et al., 2018).

DISCUSSION

Interpretation of results. The integrated framework demonstrates that sustainability in pharmaceutical supply chains is achievable through simultaneous attention to measurement, technology, governance, and circular practices. The synergy of these elements creates a reinforcing system: trusted data (via blockchain and sensors) enables credible sustainability claims; credible claims facilitate collaborative governance and socially aligned profit-sharing; collaboration underwrites investments in circularity and process improvements that reduce waste, thus reinforcing environmental and economic performance (Carter & Rogers, 2008; Cole et al., 2019; Dahan et al., 2010).

Trade-offs and counter-arguments. There are important trade-offs and counter-arguments that must be engaged. For instance, implementing blockchain and sensor networks entails upfront costs, complexity, and potential privacy concerns — especially where patient-level data are implicated (Cole et al., 2019). Critics argue that technological solutions may simply shift costs onto smaller suppliers or developing-country partners, exacerbating inequities (Mani & Gunasekaran, 2018). The framework addresses these risks by recommending collaborative financing models, graduated implementation strategies, and supplier development programs that build capacity rather than exclude (Cole & Aitken, 2019; Banik et al., 2020).

Measurement challenges. Measuring sustainability remains contentious because different stakeholders emphasize different indicators and because regulatory constraints create measurement discontinuities across jurisdictions (Ahi & Searcy, 2015; Govindan et al., 2013). The article proposes pragmatic, descriptive criteria rather than prescriptive indices to accommodate heterogeneity and recommends using multi-criteria decision-support tools to account for ambiguity and stakeholder preferences (Govindan et al., 2013; Bai et al., 2019).

Governance complexity. Institutional complexity is a central challenge. Aligning corporate incentives with public health often requires regulatory reform, novel contracting arrangements, and trust-building among actors — processes that can be slow and politically contested (Dahan et al., 2010; Ding et al., 2018). The framework positions corporate–NGO collaboration as a bridge to expedite trust and legitimacy, while acknowledging that such partnerships must be carefully structured to avoid capture or mission drift.

Policy implications. Policymakers can enable transitions by lowering barriers to data-sharing where privacy concerns are mitigated, creating incentives for circular packaging, and supporting pilot programs that demonstrate the public-health value of sustainability investments (Ding et al., 2018; Ciulli et al., 2020). Regulation that rewards or mandates traceability for high-risk pharmaceuticals would accelerate blockchain adoption where it creates clear public benefit (Cole et al., 2019).

Limitations of the present work. The study is conceptual and synthesizes existing literature rather than presenting new empirical data. While it draws on authoritative sources across technology, governance, and sustainability, the efficacy of proposed mechanisms needs empirical validation across diverse geographic, regulatory, and market contexts. Additionally, the references supplied partly determine the scope; other relevant work outside this list may offer further nuance.

Future research agenda. The article suggests several research directions: empirical testing of the framework through multi-case studies and longitudinal field experiments; simulation and agent-based modeling of collaborative profit-sharing mechanisms under demand shocks; controlled pilots of blockchain-enabled traceability for select pharmaceutical product lines; and comparative policy analyses to determine which regulatory instruments most effectively align firm incentives with public-health outcomes (Ding, 2018; Chowdhury, 2025; Ciulli et al., 2020).

CONCLUSION

This article has articulated a comprehensive framework for sustainable pharmaceutical supply chain management that integrates measurement, governance, technology, and circularity. It synthesizes foundational sustainability theories with sector-specific imperatives and practical technological enablers to present an actionable blueprint: evaluate suppliers with triple-bottom-line criteria tailored to pharmaceutical risk profiles; adopt digital transparency tools selectively where provenance and temperature integrity are critical; and build collaborative governance structures that internalize public-health outcomes into profit allocation. While implementation requires careful attention to costs, equity, and regulatory contexts, the potential payoffs are substantial: lower waste, improved health outcomes, and resilient firms better equipped for future shocks. The research agenda laid out invites empirical validation and policy experimentation. By aligning technological innovation with socially embedded governance, the pharmaceutical sector can move toward supply chains that are ethical, resilient, and sustainable.

REFERENCES

1. Carter, C., & Rogers, D.S. (2008). A framework of sustainable supply chain management: moving toward new theory. International Journal of Physical Distribution & Logistics Management, 38(5), 360-387.
2. Chaudhuri, A. (2015). Supply chain innovations in healthcare. Innovations in healthcare management: Cost-effective and sustainable solutions, 261-272.
3. Closs, D.J., Speier, C., & Meacham, N. (2011). Sustainability to support end-to-end value chains: the role of supply chain management. Journal of the Academy of Marketing Science, 39, 101-116.
4. Cole, R., Stevenson, M., & Aitken, J. (2019). Blockchain technology: implications for operations and supply chain management. Supply Chain Management: An International Journal, 24(4), 469-483.
5. Dahan, N.M., Doh, J.P., Oetzel, J., & Yaziji, M. (2010). Corporate-NGO collaboration: Co-creating new business models for developing markets. Long Range Planning, 43(2-3), 326-342.
6. Das, D. (2017). Development and validation of a scale for measuring Sustainable Supply Chain Management practices and performance. Journal of Cleaner Production, 164, 1344-1362.
7. Ding, B. (2018). Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains. Process Safety and Environmental Protection, 119, 115-130.
8. Ding, H., Wang, L., & Zheng, L. (2018). Collaborative mechanism on profit allotment and public health for a sustainable supply chain. European Journal of Operational Research, 267(2), 478-495.
9. Shou, Y., Shao, J., Lai, K.-h., Kang, M., & Park, Y. (2019). The impact of sustainability and operations orientations on sustainable supply management and the triple bottom line. Journal of Cleaner Production, 240, 118280.
10. Padhi, S.S., Pati, R.K., & Rajeev, A. (2018). Framework for selecting sustainable supply chain processes and industries using an integrated approach. Journal of Cleaner Production, 184, 969–984.
11. Govindan, K., Khodaverdi, R., & Jafarian, A. (2013). A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. Journal of Cleaner Production, 47, 345–354.
12. Burki, U., Ersoy, P., & Dahlstrom, R. (2018). Achieving triple bottom line performance in manufacturer-customer supply chains: Evidence from an emerging economy. Journal of Cleaner Production, 197, 1307–1316.
13. Kusi-Sarpong, S., Gupta, H., & Sarkis, J. (2018). A supply chain sustainability innovation framework and evaluation methodology. International Journal of Production Research, 57, 1990–2008.
14. Sarkis, J., & Dhavale, D.G. (2015). Supplier selection for sustainable operations: A triple-bottom-line approach using a Bayesian framework. International Journal of Production Economics, 166, 177–191.
15. Ahi, P., & Searcy, C. (2015). Assessing sustainability in the supply chain: A triple bottom line approach. Applied Mathematical Modelling, 39, 2882–2896.
16. Mani, V., & Gunasekaran, A. (2018). Four forces of supply chain social sustainability adoption in emerging economies. International Journal of Production Economics, 199, 150–161.
17. Cole, R., & Aitken, J. (2019). Selecting suppliers for socially sustainable supply chain management: post-exchange supplier development activities as pre-selection requirements. Production Planning & Control, 30, 1184–1202.
18. Chowdhury, W. A. (2025). Blockchain for Sustainable Supply Chain Management: Reducing Waste Through Transparent Resource Tracking. Journal of Procurement and Supply Chain Management, 4(2), 28–34.

https://doi.org/10.58425/jpscm.v4i2.435

19. Bai, C., Kusi-Sarpong, S., Badri Ahmadi, H., & Sarkis, J. (2019). Social sustainable supplier evaluation and selection: A group decision-support approach. International Journal of Production Research, 1–22.
20. Banik, A., Taqi, H. M. M., Ali, S. M., Ahmed, S., Garshasbi, M., & Kabir, G. (2020). Critical Success Factors for Implementing Green Supply Chain Management in the Electronics Industry: An Emerging Economy Case. International Journal of Logistics Research and Applications. doi:10.1080/13675567.2020.1839029.
21. Barbosa, M. W., de la Calle Vicente, A., Ladeira, M. B., & Valadares de Oliveira, M. P. (2018). Managing Supply Chain Resources with Big Data Analytics: A Systematic Review. International Journal of Logistics Research and Applications, 21(3), 177–201.
22. Cabernard, L., Pfister, S., & Hellweg, S. (2019). A New Method for Analyzing Sustainability Performance of Global Supply Chains and Its Application to Material Resources. Science of The Total Environment, 684, 164–177.
23. Cesur, E., Cesur, M. R., Kayikci, Y., & Mangla, S. K. (2020). Optimal Number of Remanufacturing in a Circular-Economy Platform. International Journal of Logistics Research and Applications. doi:10.1080/13675567.2020.1825656.
24. Chen, X., Li, S., & Wang, X. (2020). Evaluating the Effects of Quality Regulations on the Pharmaceutical Supply Chain. International Journal of Production Economics, 230, 107770.
25. Ciulli, F., Kolk, A., & Boe-Lillegraven, S. (2020). Circularity Brokers: Digital Platform Organizations and Waste Recovery in Food Supply Chains. Journal of Business Ethics, 167(2), 299–377.
26. Gao, L., Wang, J., He, H., & Wang, S. (2021). Do Motives Contribute to Sustainable Supply Chain Management? A Motive–Ability–Opportunity Triangle Research Perspective. International Journal of Logistics Research and Applications. doi:10.1080/13675567.2021.1914565.
27. Giannakis, M., & Papadopoulos, T. (2016). Supply Chain Sustainability: A Risk Management Approach. International Journal of Production Economics, 171, 455–470.
28. Heinz, F. X., & Stiasny, K. (2021). Profiles of current COVID-19 vaccines. Wiener Klinische Wochenschrift, pp.1-13.
29. INTERNATIONAL JOURNAL OF LOGISTICS RESEARCH AND APPLICATIONS (page reference as provided).
30. Padhi, S. S.; Pati, R. K.; Rajeev, A. Framework for selecting sustainable supply chain processes and industries using an integrated approach. Journal of Cleaner Production (2018), 184, 969–984.
31. Dai, D., Wu, X., & Si, F. (2021). Complexity analysis of cold chain transportation in a vaccine supply chain considering activity inspection and time-delay. Advances in Difference Equations.
32. Burki, U.; Ersoy, P.; Dahlstrom, R. (2018). Achieving triple bottom line performance in manufacturer-customer supply chains: Evidence from an emerging economy. Journal of Cleaner Production, 197, 1307–1316.
33. Chen, Y.; Wu, Q.; Shao, L. (Year not specified). Urban cold-chain logistics demand predicting model based on improved neural network model. International Journal of Metrology, Quality and Engineering.
34. Emergentcold. (2023). Cold chain: Trends 2024. https://emergentcoldlatam.com/en/cold-chain-key-trends-in-2024
35. Heinz, F.X., & Stiasny, K. (2021). Profiles of current COVID-19 vaccines. Wiener Klinische Wochenschrift, pp. 1–13.
36. Dai, D.; Wu, X.; Si, F. (2021). Complexity analysis of cold chain transportation in a vaccine supply chain considering activity inspection and time-delay. Advances in Difference Equations.