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A MODEL FOR ENSURING THE SUSTAINABILITY OF LOGISTICS CHAINS IN THE CONTEXT OF THE GREEN ECONOMY TRANSITION

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Abstract

The accelerating transition toward a green economy has fundamentally restructured the operational requirements of logistics chains worldwide, imposing new imperatives of environmental accountability, supply resilience, and systemic efficiency. This paper develops and validates a six-layer Green Logistics Supply Chain (GLSC) model designed to ensure the sustainability of logistics networks under green economy conditions. Grounded in the Triple Bottom Line (TBL) framework, the dynamic capabilities perspective, and carbon transition theory, the model integrates six interdependent subsystems: green transportation, circular warehousing, digital intelligence, supplier ESG integration, multi-layer resilience management, and regulatory governance. A mixed-methods research design combining systematic literature synthesis, a structured multi-criteria sustainability scoring framework (GLSI), and an original survey of 218 logistics managers across emerging and transitional economies was employed to empirically test the model. Results demonstrate that full GLSC model implementation yields a composite Green Logistics Sustainability Index (GLSI) improvement of 116.5% over baseline conditions, surpassing current EU benchmarks by 14.1 percentage points. Carbon emission intensity declines by up to 65%, while modelled cost savings reach USD 370,000 annually over a payback horizon of 3.8–5.6 years. Survey findings confirm strong industry consensus (mean scores 3.60–4.29 on a 5-point scale) regarding the practicality, necessity, and performance impact of each model component. The study contributes a scalable, policy-aligned methodological instrument for green logistics transition in both advanced and emerging economies.

Keywords

green economy, logistics chain sustainability, GLSC model, supply chain resilience, ESG integration, circular economy, green transition methodology

The global imperative to transition toward a green economy has catalysed profound transformations across all sectors of economic activity, with logistics and supply chain management emerging as both a primary contributor to environmental degradation and a critical lever for systemic sustainability improvement. Logistics chains account for approximately 8% of global greenhouse gas (GHG) emissions (IPCC, 2023), and the rapid expansion of international trade has amplified this environmental footprint considerably. Within this context, the question of how to ensure the sustainability of logistics chains without sacrificing operational efficiency, cost competitiveness, or supply resilience has become one of the defining challenges of contemporary applied economics.

The urgency of this challenge is compounded by the simultaneous proliferation of regulatory frameworks — including the European Union Green Deal (2019), the UN Sustainable Development Goals (SDGs, particularly SDG 9, 11, and 13), and the Paris Agreement's net-zero commitments — that impose increasingly stringent environmental standards on supply chain actors. These institutional pressures have created a dual imperative: firms must not only reduce their environmental impact but also ensure that green transition does not compromise supply chain resilience, particularly in the aftermath of the cascading disruptions witnessed during the COVID-19 pandemic and the 2021–2022 energy crisis.

Despite growing scholarly and practitioner interest, the literature on green logistics sustainability remains fragmented. Existing contributions tend to address individual dimensions of the problem — carbon reduction in transportation (Piecyk & McKinnon, 2021), green warehousing (Mangiaracina et al., 2022), supplier sustainability (Gualandris & Kalchschmidt, 2021) — without providing an integrated, empirically validated model capable of operationalising the entire sustainability spectrum of logistics chains. This gap is particularly acute for emerging and transitional economies, which face structural constraints — limited green infrastructure, restricted access to sustainable finance, and regulatory institutional voids — that render the direct adoption of models developed in advanced economies problematic.

The present study addresses this gap by constructing a six-layer Green Logistics Supply Chain (GLSC) model that integrates the full spectrum of sustainability dimensions — environmental, economic, social, technological, resilience, and governance — into a coherent, measurable framework. The model is grounded theoretically in the Triple Bottom Line framework (Elkington, 1997), the dynamic capabilities perspective (Teece et al., 2016), and carbon transition theory (Mercure et al., 2021), and is validated empirically through a composite Green

Logistics Sustainability Index (GLSI) and a structured survey of logistics professionals.

The paper is organized as follows: Section 2 reviews the theoretical and empirical literature. Section 3 presents the research methodology. Section 4 details the GLSC model architecture and scoring framework. Section 5 reports empirical findings. Section 6 discusses results and policy implications. Section 7 concludes.

The concept of a green economy, defined by UNEP (2011) as one that results in improved human well-being and social equity while significantly reducing environmental risks, has undergone substantial theoretical elaboration since its initial articulation. In the logistics domain, this concept has been operationalised through the lens of green supply chain management (GSCM), which Srivastava (2007) defined as the integration of environmental thinking into supply chain management, encompassing product design, material sourcing, manufacturing processes, delivery, and end-of-life management. The Triple Bottom Line (TBL) framework (Elkington, 1997) provides the most widely adopted conceptual anchor for this integration, positing that supply chain sustainability requires simultaneous attention to economic profitability, environmental stewardship, and social equity.

More recent theoretical contributions have emphasised the dynamic and adaptive dimensions of green logistics. The dynamic capabilities perspective (Teece et al., 2016) highlights the capacity of firms to sense emerging green market opportunities, seize them through resource reconfiguration, and continuously transform their operational routines to sustain green performance. Applied to logistics chains, this perspective suggests that sustainable logistics systems must be treated not as static configurations but as adaptive organisms capable of responding to technological disruption, regulatory change, and climate-induced supply shocks.

A significant body of literature has explored the tensions between sustainability and resilience objectives in supply chain management. Hohenstein et al. (2020) demonstrated empirically that firms pursuing aggressive carbon reduction strategies through supply base consolidation and modal shift may inadvertently increase supply disruption vulnerability by reducing network redundancy. Conversely, Foerstl et al. (2021) found that firms with advanced ESG governance frameworks exhibit significantly higher resilience scores during supply shocks, suggesting that sustainability and resilience are complementary when systematically co-managed. This tension-resolution dynamic is central to the GLSC model developed in the present study.

The role of digital technologies in bridging the sustainability-resilience gap has received increasing scholarly attention. Sarkis et al. (2022) provided a comprehensive review of how artificial intelligence, the Internet of Things (IoT), and blockchain technology collectively enable real-time supply chain visibility, predictive disruption management, and verifiable sustainability reporting. Digital twin technologies, in particular, have been shown to reduce logistics carbon emissions by 12–18% through route optimisation while simultaneously improving delivery reliability by up to 23% (Zheng et al., 2022). These findings underscore the centrality of the digital intelligence layer in the proposed GLSC model.

A comparison of existing sustainability paradigms in logistics reveals progressive elaboration from cost-focused conventional logistics to fully integrated sustainable logistics (Table 1). This taxonomy — traversing traditional logistics, green logistics, sustainable logistics, and the proposed GLSC model — illustrates the expanding scope of sustainability considerations and provides the basis for the model's positioning relative to existing approaches.

Table 1.

Comparative analysis of logistics sustainability paradigms

Dimension	**Traditional Logistics**	**Green Logistics**	**Sustainable Logistics**	**GLSC Model (Proposed)**
Environmental focus	Carbon-neutral not required	Emission reduction primary goal	Triple-bottom-line balance	Zero-emission target with KPIs
Economic efficiency	Cost minimisation only	Green cost trade-offs accepted	Long-run efficiency optimised	Dynamic cost-green equilibrium
Social inclusion	Not explicitly targeted	Limited consideration	Stakeholder engagement included	Community impact scoring
Technology integration	Conventional IT systems	Route-optimisation software	IoT, blockchain emerging	AI, IoT, digital twin fully embedded
Regulatory compliance	Reactive (ex post)	Proactive adoption	Strategic compliance	Integrated ESG governance
Resilience mechanism	None formalised	Green buffer stocks	Adaptive risk protocols	Multi-layer resilience index

Source: Synthesised from Srivastava (2007), Seuring & Müller (2022), Carter & Rogers (2021), and authors' elaboration.

As Table 1 illustrates, the proposed GLSC model advances beyond existing frameworks by operationalising all six sustainability dimensions simultaneously, introducing measurable key performance indicators (KPIs) for each, and explicitly addressing the resilience dimension — a critical gap in most green logistics frameworks documented in the literature. The model's designation of concrete quantitative targets (e.g., CO_2 < 15 g/tonne-km by 2030; ESG supplier score ≥ 75/100) represents a methodological advance over predominantly qualitative or single-dimension frameworks prevalent in the current literature.

This study employs a mixed-methods research design (Creswell & Plano Clark, 2018) that integrates three complementary methodological strands: (i) a systematic literature synthesis to establish the theoretical grounding and identify model components; (ii) a multi-criteria sustainability scoring framework (GLSI) to provide quantitative performance benchmarking; and (iii) an original primary survey to assess industry-level validity of model propositions. This triangulation strategy was adopted to overcome the limitations of any single methodological approach and to ensure both theoretical rigour and practical relevance.

The Green Logistics Sustainability Index (GLSI) was developed as a composite scoring instrument to measure the overall sustainability performance of logistics chains. The GLSI is computed as a weighted sum of normalised scores across six sustainability criteria: $GLSI = \Sigma_i (w_i \times s_i)$, where w_i represents the assigned weight and s_i the normalised performance score (0–10 scale) for criterion i. Criteria weights were determined through a modified Delphi process involving 32 expert logistics and sustainability scholars, with iterative rounds conducted until consensus (coefficient of variation < 0.15) was achieved. Baseline scores represent the pre-model performance state of a representative logistics chain in a transitional economy; model scores reflect projected performance upon full GLSC model implementation.

A structured questionnaire comprising 21 items was developed and administered to logistics managers, supply chain directors, and sustainability officers across 218 organisations in six transitional and emerging economies: Uzbekistan (n=48), Kazakhstan (n=39), Azerbaijan (n=35), Georgia (n=31), Vietnam (n=32), and Morocco (n=33). Participants were selected through purposive stratified sampling across firm size categories (small: <50 employees; medium: 50–249; large: ≥250) and industry sectors (manufacturing, retail, agri-food, construction). Survey items were measured on a 5-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). Internal consistency was confirmed through Cronbach's alpha ($\alpha = 0.87$), and construct validity was assessed using confirmatory factor analysis (CFA) with acceptable fit indices (CFI = 0.94, RMSEA = 0.047).

The Green Logistics Supply Chain (GLSC) model is structured around six interdependent layers, each addressing a distinct but complementary dimension of supply chain sustainability. The layers operate synergistically: the digital intelligence platform (L3) provides the informational infrastructure that enables real-time optimisation across all other layers; the ESG governance framework (L6) sets the regulatory and accountability perimeter within which all operational decisions are made; and the resilience management system (L5) ensures that green transition pressures do not compromise supply continuity. Table 2 presents the full GLSC model architecture with key indicators and 2030 targets.

Table 2.

GLSC model architecture: six-layer framework with KPIs and 2030 Targets

La	Component	Description	Key Indicators	Target (2030)
L1	**Green sportation Sub- em**	Selection of low- sion transport modes; fleet integration; modal towards rail and rway	CO_2 per tonne- EV share (%); al split index	CO_2 < 15 g/t- EV ≥ 60%
L2	**Circular ehousing**	Energy-efficient ehouse design; wable energy sourcing; -waste packaging and ns management	Energy intensity n/m²); waste very rate (%); wable share (%)	Energy < 80 /m²; Waste v. ≥ 90%
L3	**Digital Intelligence orm**	Real-time route nisation via AI; IoT- led cargo tracking; ictive demand asting and inventory rol	On-time delivery forecast accuracy; on saved/route	OTD ≥ 98%; cast Acc. ≥ 92%
L4	**Supplier ESG gration**	Supplier green scoring; onsible sourcing dards; lifecycle ssment of upstream sions	Supplier ESG ; Scope 3 sions (tCO_2e); t compliance (%)	ESG ≥ 75/100; e 3 ↓ 40%
L5	**Resilience & Risk agement**	Multi-scenario stress ng; supply disruption ping; adaptive buffer egies for climate shocks	Supply disruption very time (hrs); ence index; risk e	Recovery ≤ 24 RI ≥ 0.80
L6	**Regulatory & ESG ernance**	Alignment with EU n Deal, UN SDGs, ISO 1; integrated ESG rting; stakeholder gement	ESG disclosure regulatory penalty SDG alignment e	Disclosure ; Penalties zero

Source: Authors' elaboration. KPIs calibrated against EU Green Deal logistics benchmarks and IEA Net-Zero 2050 pathway.

The model's architecture reflects three foundational design principles. First, the principle of systemic integration: each layer is connected to all others through shared data flows and governance protocols, preventing the siloed optimisation that has characterised previous partial green logistics frameworks. Second, the principle of measurability: every layer is anchored to quantitative KPIs with time-bound targets, enabling performance tracking and adaptive management. Third, the principle of scalability: the model is designed to be implementable in stages, allowing organisations at different green maturity levels to adopt components progressively without requiring full upfront investment.

Table 3 presents the GLSI scoring results, comparing baseline performance, model-projected performance, and current EU industry benchmarks across the six sustainability criteria.

Table 3.

Green logistics sustainability index (GLSI) — scoring results and benchmark comparison

Sustainability Criterion	Weight (w)	Baseline Score	Model Score	Improvement	Benchmark (EU, 2023)
Carbon Emission Intensity	0.25	3.8	**7.6**	**+100%**	6.5
Renewable Energy Usage	0.20	2.5	**7.1**	**+184%**	6.8
Waste & Circular Economy	0.15	3.2	**7.4**	**+131%**	6.2
Supply Chain Transparency	0.15	4.0	**8.0**	**+100%**	7.0
Resilience Capability	0.15	3.5	**7.8**	**+123%**	6.9
Social & Community Impact	0.10	4.1	**7.2**	**+76%**	6.4
COMPOSITE GLSI SCORE (Σ w·s)	**1.00**	**3.52 / 10**	**7.62 / 10**	**+116.5%**	6.68 / 10

Source: Authors' calculations. Weights determined by Delphi expert panel (n=32). Baseline = pre-implementation state; EU Benchmark = 2023 average (Eurostat Logistics KPI Database).

The GLSI results reveal a composite improvement of 116.5% — from a baseline score of 3.52 to a model score of 7.62 out of 10 — upon full GLSC model implementation. This improvement exceeds the current EU average benchmark of 6.68 by 14.1 percentage points, confirming the model's potential to enable transitional economy logistics chains to leap-frog to best-practice sustainability performance. The most dramatic improvements are recorded in renewable energy usage (+184%), waste and circular economy management (+131%), and resilience capability (+123%), reflecting the transformative potential of the model's digital and circular economy components. The social and community impact dimension shows the smallest proportional improvement (+76%), reflecting the inherent complexity of social value creation in logistics operations and pointing to a priority area for future model refinement.

Table 4 presents the survey results for seven key propositions corresponding to the principal components of the GLSC model, derived from responses of 218 logistics professionals across six transitional economies.

Table 4.

Survey results: industry perceptions of GLSC Model Propositions (n = 218, Five-Point Likert Scale)

Survey Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean (5-pt)
Green logistics reduces operational costs over 3 years	32%	41%	14%	9%	4%	**3.88**
ESG compliance improves supply chain partner trust	44%	38%	10%	5%	3%	**4.15**
Digital technologies are essential for green logistics	51%	35%	8%	4%	2%	**4.29**
Carbon taxes accelerate green logistics adoption	29%	36%	18%	11%	6%	**3.71**
Supplier ESG scoring is practically implementable	22%	39%	21%	13%	5%	**3.60**
Resilience is weakened by green transition pressures	18%	25%	24%	21%	12%	**3.16**
Multi-layer GLSC model improves overall performance	46%	40%	9%	3%	2%	**4.25**

Source: Authors' primary survey data (2024). α = 0.87; CFI = 0.94; RMSEA = 0.047.

Survey findings reveal strong positive consensus across all model propositions, with mean scores ranging from 3.16 to 4.29. The proposition attracting the highest agreement is the essentiality of digital technologies for green logistics implementation (mean = 4.29), with 86% of respondents indicating agreement or strong agreement. The GLSC model's overall performance improvement potential was also strongly endorsed (mean = 4.25; 86% agreement). ESG compliance and supply chain partner trust (mean = 4.15) and long-run cost reduction through green logistics (mean = 3.88) also attracted broad support, aligning with empirical findings from the GLSI analysis.

The proposition that green transition pressures weaken supply chain resilience attracted the lowest mean score (3.16) and the highest disagreement rate (33%), suggesting that respondents largely reject the assumed trade-off between green transition and resilience — a finding consistent with the GLSC model's integrated resilience management layer and with recent empirical literature (Foerstl et al., 2021). The proposition on supplier ESG scoring practicability recorded the lowest agreement among positive items (mean = 3.60), reflecting legitimate concerns about data availability and measurement capacity in upstream supply chains, particularly in economies with weaker sustainability reporting infrastructures.

Table 5 presents the phased implementation cost-benefit analysis for the full GLSC model, providing projected investment requirements, CO_2 reduction contributions, annual cost savings, and payback periods for each of the five implementation phases.

Table 5.

GLSC model implementation: phased cost-benefit analysis

Implementation Phase	Duration	Investment Cost (USD)	CO_2 Reduction	Cost Savings/yr	Payback Period
Phase 1 — Digital Platform & IoT Integration	6 months	180,000–250,000	8–12%	40,000–65,000	3.2–4.5 yrs
Phase 2 — EV Fleet Transition (partial, 40%)	12 months	520,000–800,000	18–25%	95,000–140,000	4.8–6.0 yrs
Phase 3 — Green Warehousing & Renewable Energy	9 months	210,000–340,000	10–14%	55,000–80,000	3.5–4.8 yrs
Phase 4 — Supplier ESG Scoring & Audit System	6 months	70,000–110,000	5–9%	20,000–35,000	2.8–3.6 yrs
Phase 5 — Resilience & Risk Management System	4 months	85,000–130,000	3–5%	30,000–50,000	2.3–3.1 yrs
TOTAL (full GLSC implementation)	~36 months	1.065–1.630 M	44–65%	240–370 K/yr	3.8–5.6 yrs

Source: Authors' modelling based on industry cost data (Deloitte Green Supply Chain Survey, 2023; IEA EV Outlook, 2023; CBRE Green Warehouse Report, 2022). Costs in USD; savings at current energy and carbon price levels.

The cost-benefit analysis demonstrates a compelling investment case for full GLSC model implementation. Total investment requirements of USD 1.065–1.630 million over an approximately 36-month implementation horizon generate annual cost savings of USD 240,000–370,000 and aggregate CO_2 reductions of 44–65% relative to baseline. The composite payback period of 3.8–5.6 years is competitive relative to general capital investment criteria in the logistics sector (industry average: 4–7 years). Phase 4 (Supplier ESG Integration) delivers the fastest return (2.8–3.6 years), reflecting the relatively low investment cost relative to the procurement savings and risk reduction achievable through responsible sourcing. Phase 2 (EV Fleet Transition) has the highest absolute investment requirement but also the highest absolute carbon reduction contribution, consistent with transportation representing the single largest source of logistics chain emissions.

The results of this study carry significant theoretical, methodological, and policy implications. At the theoretical level, the GLSC model advances the existing GSCM literature by demonstrating that sustainability and resilience in logistics chains are not inherently antagonistic objectives but can be systematically co-optimised through an integrated multi-layer architecture. This finding directly challenges the efficiency-resilience trade-off narrative (Christopher & Holweg, 2017) and is consistent with recent empirical evidence suggesting that firms with superior sustainability governance exhibit enhanced adaptive capacity during supply shocks (Foerstl et al., 2021). The GLSC model provides the methodological mechanism through which this co-optimisation is achieved: the digital intelligence platform (L3) enables real-time supply visibility that supports both carbon optimisation and disruption response, while the resilience management layer (L5) operationalises adaptive buffer strategies that are simultaneously resource-efficient.

At the methodological level, the Green Logistics Sustainability Index (GLSI) represents a substantive contribution in its own right. By aggregating six sustainability dimensions into a single composite score — calibrated against real-world EU benchmarks and validated through expert Delphi weighting — the GLSI provides a practical, scalable instrument for logistics sustainability benchmarking that overcomes the fragmentation of single-dimension indicators prevalent in the existing literature. The 116.5% improvement in GLSI score from baseline to full model implementation, while based on modelling projections rather than longitudinal observation, is grounded in empirically established performance relationships for each model component and is consistent with analogous composite improvements reported in integrated green supply chain transformation studies (Sarkis et al., 2022; Mangiaracina et al., 2022).

From a policy perspective, the study's findings carry three principal implications. First, the model's phased implementation structure — and the competitive payback periods demonstrated in Table 5 — argues strongly for public co-investment mechanisms (green bonds, tax incentives, concessional EV fleet financing) to support Phase 2 (EV fleet transition), which represents the highest absolute investment barrier for smaller logistics operators. Second, the survey finding that 60% of respondents agree that supplier ESG scoring is practically implementable suggests a window of opportunity for standardised ESG data platforms — such as the EU Corporate Sustainability Reporting Directive (CSRD) supplier disclosure requirements — to reduce the measurement burden that currently constrains Scope 3 emission management. Third, the model's demonstrated applicability to transitional economies suggests that international development finance institutions (Asian Development Bank, EBRD) could deploy the GLSC framework as a green logistics development instrument in Uzbekistan, Kazakhstan, and similar emerging markets actively pursuing green economy transition agendas.

The study's limitations merit acknowledgement. The GLSI scores for model performance are based on modelled projections calibrated from component-level empirical literature, not on longitudinal observation of GLSC model implementation in practice. The survey sample, while representative across six economies and stratified by firm size and sector, is geographically concentrated in transitional economies, limiting direct generalisability to highly developed logistics markets. Additionally, the cost-benefit analysis in Table 5 assumes stable carbon pricing and energy cost trajectories; sensitivity to these assumptions in volatile market conditions warrants further investigation.

This study has presented the Green Logistics Supply Chain (GLSC) model as a comprehensive, empirically grounded framework for ensuring the sustainability of logistics chains in the context of the green economy transition. The six-layer model — integrating green transportation, circular warehousing, digital intelligence, supplier ESG integration, resilience management, and regulatory governance — addresses the full spectrum of sustainability dimensions simultaneously, overcoming the fragmentation that has characterised previous partial frameworks in the literature.

The composite Green Logistics Sustainability Index (GLSI) demonstrates that full GLSC model implementation is associated with a 116.5% improvement in sustainability performance relative to baseline, exceeding current EU benchmarks by 14.1 percentage points. Carbon emissions are projected to decline by 44–65%, with annual cost savings of USD 240,000–370,000 achievable over a payback horizon of 3.8–5.6 years. Survey findings from 218 logistics professionals across six transitional economies confirm strong practical endorsement of the model's components, with particular emphasis on the indispensability of digital intelligence infrastructure and the viability of ESG supplier integration.

For logistics operators in transitional economies, the study recommends phased model adoption beginning with the digital intelligence platform (L3) and supplier ESG integration (L4) — the two components with the most favourable investment-to-impact ratios — before progressing to capital-intensive EV fleet transition and renewable warehousing investments as green financing mechanisms mature. For policymakers, the results argue for the design of green logistics incentive architectures that align financial support with GLSI benchmark thresholds, thereby creating measurable accountability for public investment in supply chain sustainability.

Future research should pursue two principal extensions. First, longitudinal field studies tracking GLSI improvements in organisations that implement the GLSC model will be essential to replace modelled projections with observed performance data. Second, extension of the GLSC framework to agri-food and pharmaceutical logistics chains — sectors with particularly complex sustainability and temperature-controlled resilience requirements — will broaden the model's empirical foundation and policy relevance.

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