IMPROVING SUSTAINABILITY IN LOGISTICS THROUGH ARTIFICIAL INTELLIGENCE AND DISTRIBUTED LEDGER TECHNOLOGIES

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ABSTRACT
As global pressure increases for sustainable and transparent supply chains, logistics organisations are exploring ways to strengthen environmental, social and governance (ESG) performance. This article examines how artificial intelligence (AI) and distributed ledger technologies (DLT) contribute to ESG integration in logistics. The study applies a qualitative desk research approach based on secondary data from 2017–2025, including sustainability reports, port authority publications, and the industry press. The comparative case analysis covers four Baltic logistics actors: the Port of Klaipėda (Lithuania), Vlantana (Lithuania), the Freeport of Riga/Baltic Container Terminal (Latvia), and HHLA TK Estonia (Estonia). The findings show that Klaipėda's LNG, OPS, and hydrogen projects enhance environmental outcomes; the Vlantana Norge case exposes social and governance compliance risks; and Riga and Tallinn demonstrate governance-oriented digitalisation through 5G networks and blockchain documentation. AI primarily supports efficiency and risk detection, while DLT secures the transparency and auditability of ESG data. Together, they function as complementary enablers of ESG reporting, though broader adoption requires regulatory alignment, interoperability, and investment in the digital infrastructure.
KEY WORDS: *ESG, logistics, artificial intelligence, distributed ledger*.

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Introduction

Sustainable development is increasingly recognised as a central paradigm in both the academic discourse and practical policy implementation, requiring economic growth to be aligned with environmental protection, social equity and effective governance. The concept of environmental, social and governance (ESG) performance has become a widely adopted framework for assessing corporate responsibility and long-term value creation, extending beyond purely financial outcomes. ESG has been embedded in investment decisions, regulatory standards and operational strategies across industries, reflecting the evolving priorities of stakeholders who demand transparency, ethical conduct and measurable sustainability outcomes (Eccles, Klimenko, 2019).

The logistics sector, encompassing freight transportation, warehousing, inventory management, and supply chain coordination, is a critical enabler of global economic activity. However, it is also one of the most resource-intensive and environmentally impactful industries. According to the International Energy Agency (IEA, 2023), transport contributes approximately 24% of global CO_2 emissions from fuel combustion, with freight logistics accounting for a rapidly growing proportion. Beyond the environmental concerns, logistics operations raise substantial social issues, including occupational safety, labour rights, and equitable access to infrastructure. Governance-related challenges, such as fragmentary supply chain data, non-transparent

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subcontracting arrangements and inconsistent reporting practices, further hinder accountability and stakeholder trust (Reynolds, 2024). Addressing these multi-dimensional sustainability challenges requires not only policy interventions but also systemic technological innovation.

Recent advances in digitalisation have introduced powerful tools for integrating ESG principles into logistics operations. Among these, artificial intelligence (AI) and distributed ledger technologies (DLT), including blockchain, are increasingly regarded as transformative enablers of sustainable logistics. AI offers capabilities for processing large-scale operational data, generating predictive insights, and optimising decision-making in real time. In environmental terms, AI can significantly reduce carbon emissions through dynamic route optimisation, predictive maintenance of fleets, and intelligent load planning (Wang et al., 2022). Socially, AI applications support occupational risk prediction, workforce scheduling and safety compliance monitoring. From a governance perspective, machine learning algorithms can detect anomalies in transactions, ensure compliance with sustainability standards, and automate ESG reporting.

In parallel, DLT provides a decentralised, immutable infrastructure for data recording and verification. Within ESG-oriented logistics, blockchain can trace products from origin to destination, certify the ethical sourcing of raw materials, record real-time carbon emissions, and execute smart contracts that enforce sustainability clauses automatically (Liu et al., 2024). Such functionalities address persistent issues of trust and verification in ESG reporting, mitigating the risks of 'greenwashing', and enhancing transparency across the supply chain (Alotaibi, 2024). When combined, AI and DLT create a synergistic technological architecture in which AI generates high-quality, actionable ESG data, and DLT guarantees its integrity, accessibility and auditability.

The practical relevance of these technologies is already evident in pioneering cases. For instance, the TradeLens platform, developed by IBM and Maersk, demonstrated the potential of blockchain for digitalising and securing shipping documentation, although its discontinuation in 2022 revealed institutional and scalability barriers. Start-ups such as Circulor have implemented blockchain-enabled traceability for critical minerals like cobalt, addressing both environmental and social concerns in high- risk supply chains. VeChain has deployed blockchain in the food logistics sector to ensure authenticity and track carbon footprints. These examples illustrate the feasibility of AI/DLT-driven ESG integration, but also highlight the need for systemic adoption strategies that address technological, organisational and regulatory constraints.

The problem addressed in this article is the limited empirical evidence on how artificial intelligence (AI) and distributed ledger technologies (DLT) are applied in logistics organisations in the Baltic States. Although often presented as enablers of sustainability, their concrete contribution to environmental, social and governance (ESG) outcomes remains underexplored. This raises the guiding research question: How are AI and DLT applied in logistics organisations in Lithuania, Latvia and Estonia to support the implementation of ESG principles, and what challenges affect their broader adoption?

The aim of this research is to analyse the application of artificial intelligence and distributed ledger technologies in integrating ESG principles into logistic operations.

The research methods applied in this study include a conceptual analysis of ESG in logistics, a literature review on AI and DLT applications, and an examination of case examples from four logistics organisations in the Baltic States: the Port of Klaipėda (Lithuania), Vlantana (Lithuania), the Freeport of Riga/Baltic Container Terminal (Latvia), and HHLA TK Estonia (Estonia).

1. ESG principles and digital technologies in the logistics sector

The implementation of environmental, social and governance (ESG) principles in logistics is grounded in the broader sustainability agenda that seeks to align business operations with the United Nations Sustainable Development Goals (SDGs), and regional policy frameworks such as the European Green Deal. ESG provides a structured, multidimensional assessment framework for non-financial performance, enabling firms to address environmental impact, social responsibility and governance transparency in an integrated manner (Friede, Busch, Bassen, 2015).

In logistics, the environmental dimension encompasses the mitigation of greenhouse gas (GHG) emissions, energy efficiency, resource conservation, and pollution control across transport, warehousing and distribution activities. For example, freight transport alone accounts for a significant share of CO_2 emissions in the transport sector, and improvements in fuel efficiency, modal shifts to low-emission transport and route optimisation are recognised as critical pathways to decarbonisation (McKinnon, 2018).

The social dimension includes occupational safety, fair labour conditions, equitable access to services, and community impact. This is particularly relevant in global supply chains where subcontracting practices can create gaps in compliance with labour standards (Gualandris, Klassen, Vachon, Kalchschmidt, 2015). The governance dimension relates to transparency, accountability and ethical management practices, including robust data governance, anti-corruption measures, and adherence to international reporting standards, such as the Global Reporting Initiative (GRI).

Artificial intelligence (AI) has emerged as a transformative enabler for achieving ESG objectives in logistics. By processing large and diverse datasets, AI supports operational optimisation in ways that directly improve environmental performance, such as predictive route planning that minimises fuel consumption and emissions (Abduljabbar, Dia, Liyanage, Bagloee, 2019).

AI-powered predictive maintenance can reduce unplanned downtime and extend the life cycle of transport assets, contributing to resource efficiency. Socially, AI applications in safety analytics help identify high-risk situations before accidents occur, while AI-enhanced decision support can allocate workloads to improve employee well-being. In governance, AI-based anomaly detection algorithms strengthen compliance monitoring and fraud prevention, supporting accurate and timely ESG reporting (Naz, Sharma, Dutta, 2022).

Distributed ledger technologies (DLT), including blockchain, complement AI by ensuring the traceability, integrity and verifiability of ESG-related data. In logistics, DLT enables the recording of immutable transaction histories for shipments, thereby supporting product provenance verification and the tracking of carbon footprints in real time (Tan, Lau, Wang, 2020). This capability is critical in counteracting greenwashing, as blockchain-based records provide auditable evidence for sustainability claims (Wang et al., 2024). DLT also facilitates the automation of compliance processes through smart contracts, which can enforce contractual obligations related to emissions limits, ethical sourcing, or safety standards without intermediary intervention (Saberi, Kouhizadeh, Sarkis, Shen, 2019).

The synergy between AI and DLT lies in their complementary functionalities: AI generates high- quality, actionable sustainability insights from complex operational data, while DLT secures those insights within a transparent and tamper-proof system. For instance, AI can estimate the carbon footprint of a multimodal shipment, and DLT can store this calculation alongside verified shipment data to create a permanent, auditable ESG record accessible to all stakeholders. Such integrated systems are particularly relevant as regulators and investors push for standardised ESG disclosures, as in the EU Corporate Sustainability Reporting Directive (CSRD).

Despite their potential, several barriers hinder the wide-scale adoption of AI and DLT in ESG- oriented logistics. Technical challenges include interoperability between heterogeneous data systems, scalability of blockchain networks, and ensuring AI model transparency to comply with emerging AI governance frameworks. Organisational barriers involve high initial investment costs, skills shortages, and resistance to process change. Additionally, the energy consumption of some blockchain consensus mechanisms poses an environmental paradox that must be addressed through the adoption of energy-efficient protocols (Sedlmeir, Buhl, Fridgen, Keller, 2020).

To sum up, AI and DLT represent a mutually reinforcing technological foundation for embedding ESG principles in logistics operations. However, their successful deployment requires coordinated advances in technology design, regulatory alignment, and industry-wide collaboration to develop interoperable standards and metrics. The following section applies these conceptual insights to real-world cases, illustrating both the opportunities and limitations of AI/DLT-enabled ESG integration in logistics.

2. AI and DLT for ESG in logistics organisations in the Baltic States

This empirical analysis applies a qualitative desk research approach with a comparative case study design, using secondary data from 2017 to 2025. Sources include corporate sustainability reports, port authority announcements, industry publications and verified media coverage. The aim is to identify how AI and DLT are actually enabling environmental, social and governance (ESG) outcomes in logistics operations.

Four cases, the Port of Klaipėda (Lithuania), Vlantana (Lithuania), the Freeport of Riga/Baltic Container Terminal (Latvia), and HHLA TK Estonia (Estonia), were selected for their sectoral complementarity (seaport authority, road haulage, container terminal and terminal operator) and for meeting three criteria: documented ESG initiatives or controversies, evidence of AI or DLT application, and availability of reliable public data. As the study relies solely on secondary sources, no ethical approval was required, although attention was paid to using credible and traceable materials.

Evidence from the maritime infrastructure in Klaipėda shows a clear environmental trajectory. On 9 April 2024, the port completed Lithuania's first ship-to-ship LNG bunkering: 326 cubic metres supplied by Avenir Aspiration to CMA CGM's Containerships Aurora, signalling the availability of an alternative fuel pathway in the Baltic feeder network (Klaipėda State Seaport Authority, 2024; Port Technology International, 2024; Ship & Bunker, 2024). In parallel, the port has initiated works to deliver on-shore power supply (OPS) for Ro-Ro vessels, with the electrification of quays framed explicitly as an air-pollution and CO_2-reduction measure (Offshore Energy, 2025; Klaipėda State Seaport Authority, n.d.).

In May 2025, the port announced receipt of a construction permit for a green-hydrogen production and refuelling station, intended to supply vessels and port equipment (Hydrogen Europe, 2025). These steps provide an auditable basis for environmental improvements (fuel switching, reduced at-berth emissions, and future green fuel readiness), and create data points that can be integrated into CSRD-aligned reporting once measurement systems (metered OPS consumption; LNG, H_2 dispensing logs) are in place.

The social and governance challenges characteristic of subcontracting-intensive road haulage are illustrated by Vlantana Norge. In February 2020 the Norwegian Public Roads Administration (Statens vegvesen) revoked the company's transport licences; following an appeal, the revocation was overturned in January 2021 (Statens vegvesen, 2021). Civil litigation nevertheless proceeded: by October 2021, 52 drivers had been awarded compensation at the district court (Trans.INFO, 2021); in January 2023, the media reported that Vlantana Norge had lost its appeal, and the drivers were entitled to payment with interest (Trans.INFO, 2023). The sequence underscores the difficulty of verifying working-time and pay records across borders and contractors, and, critically for this study, highlights a concrete use-case for AI and DLT: anomaly detection in timesheets and telematics (AI), combined with tamper-evident documentation (DLT), could reduce the evidentiary uncertainty of disputes, and strengthen social and governance assurance along the road-freight chain.

On the governance side of port operations, the Freeport of Riga, via BCT, has adopted private 5G for mission-critical connectivity. Public materials indicate a dedicated 5G core and radio access deployed on the terminal estate (LMT, n.d.), and a shore-to-ship maritime 5G proof-of-concept demonstrated in July 2024 (Port of Riga, 2024; Sustainable World Ports, 2024).

This connectivity layer enables low-latency, high-bandwidth data exchange (e.g. computer- vision safety analytics, equipment telemetry), which in turn feeds ESG data pipelines (asset efficiency, energy use, incident capture). While 5G is not an ESG technology yet, it enables AI applications and makes governance-quality data feasible at scale, thereby supporting CSRD-grade disclosures and external assurance (LSM.lv, 2025).

At HHLA TK Estonia, DLT has been tested in production-adjacent settings as part of Estonia's longstanding digitalisation agenda. In 2017, the Port of Tallinn piloted a paperless blockchain logistics solution (SmartLog) at Muuga Harbour, targeting faster cargo handling and data integrity across actors (Transport Events, 2017; Port Technology International, 2019). Subsequently, HHLA TK Estonia joined TradeLens (2019), even though TradeLens failed due to low cooperation between the actors; the terminal within a distri-

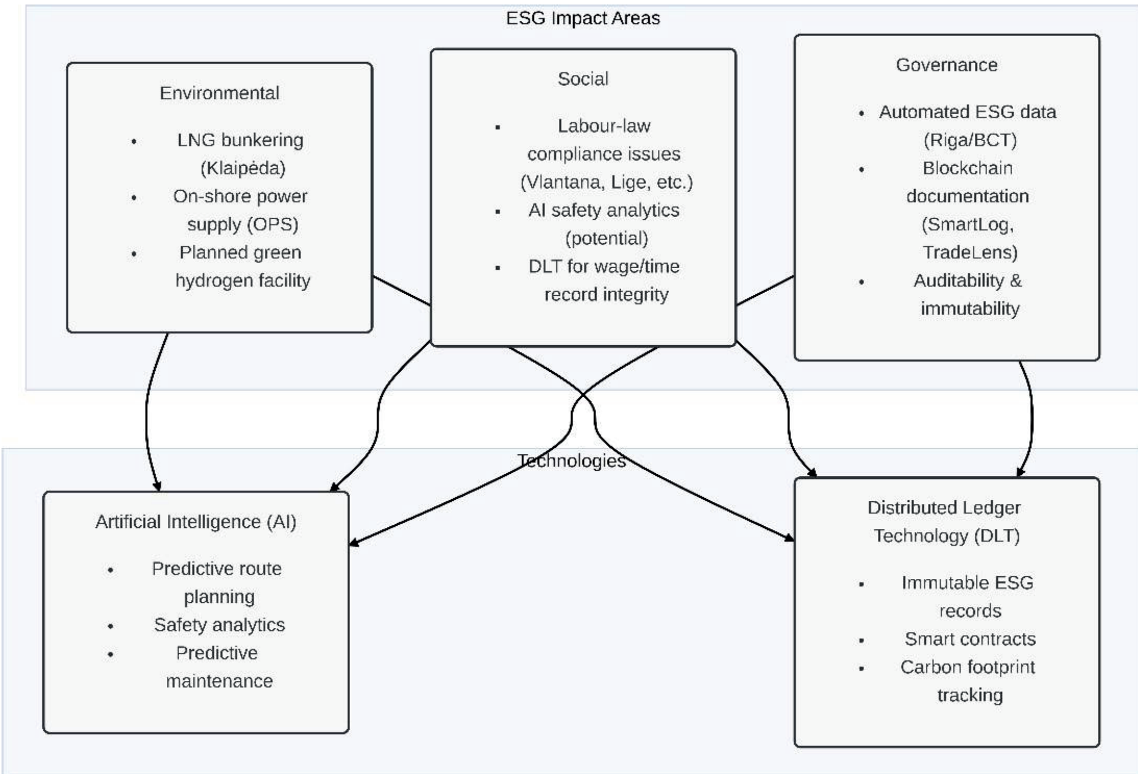

Figure 1. The enabling role of AI and DLT in ESG impact areas of logistics organisations in the Baltic States

Source: The author.

buted data-exchange ecosystem was designed to secure documentation flows and improve visibility (HHLA TK Estonia, 2019).

Together, these initiatives demonstrate the governance value of DLT in auditability and immutability, and illustrate how DLT can anchor AI-derived metrics (e.g. emissions estimates or safety KPIs) in trusted records for stakeholder reporting.

Figure 1 synthesises these observations thematically. The visual organises environmental (fuel switching and electrification in Klaipėda), social (labour-law compliance and safety-analytics pathways prompted by the Vlantana Norge litigation) and governance (5G-enabled data integrity at Riga/BCT; DLT for paperless documentation at HHLA TK Estonia) ESG impact areas, and maps AI and DLT as cross-cutting enablers, rather than as ends in themselves.

In ports and terminals, governance-grade connectivity and DLT make ESG data traceable and auditable; in road haulage and operations, AI creates measurable efficiencies and risk signals that, once anchored on trustworthy platforms, become decision-useful for regulators, customers and investors.

Conclusions

The empirical analysis confirms that artificial intelligence (AI) and distributed ledger technologies (DLT) provide concrete instruments for advancing environmental, social and governance (ESG) objectives in objectives in logistics organisations in the Baltic countries. Environmental progress is evident in Klaipėda, where LNG bunkering, on-shore power supply, and hydrogen initiatives illustrate how digital monitoring can underpin measurable emission reductions. Social and governance challenges, exemplified by the Vlantana Norge litigation, reveal persistent gaps in labour transparency, where AI- driven anomaly detection and blockchain-secured records could enhance compliance. Governance innovations in Riga and Tallinn further show that private 5G networks and blockchain pilots create the infrastructure for auditable, cross-border ESG reporting.

Overall, the findings highlight the complementary role of AI and DLT: AI generates actionable operational insights, while DLT ensures their integrity and accessibility for regulators, partners, and investors. In the Baltic context, marked by openness, reliance on global trade and strong EU regulatory pressure, this synergy represents not only a technological opportunity but also a necessity for long-term competitiveness. Still, successful adoption depends on interoperability, policy alignment and continued investment in digital infrastructure.

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LOGISTIKOS TVARUMO GERINIMAS PASITELKUS DIRBTINĮ INTELEKTĄ IR PASKIRSTYTOSIOS KNYGOS TECHNOLOGIJĄ

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Santrauka

Didėjant spaudimui užtikrinti tvarius ir skaidrius tiekimo grandinių procesus, logistikos organizacijos ieško būdų, kaip pagerinti aplinkosaugos, socialinės atsakomybės ir valdysenos (ESG) rezultatus. Šiame straipsnyje nagrinėjama, kaip dirbtinis intelektas (DI) ir paskirstytojo registro technologijos (DLT) prisideda prie ESG principų integravimo logistikos sektoriuje. Tyrime taikomas kokybinės antrinių duomenų analizės metodas, remiantis 2017–2025 m. laikotarpio tvarumo ataskaitomis, uostų direkcijų leidiniais ir pramonės spauda. Palyginamosios atvejo analizės pagrindu nagrinėjamos keturios Baltijos šalių logistikos organizacijos: Klaipėdos valstybinis jūrų uostas (Lietuva), „Vlantana“ (Lietuva), Rygos laisvojo uosto Baltijos konteinerių terminalas (Latvija) ir „HHLA TK Estonia“ (Estija). Empirinė analizė patvirtina, kad dirbtinis intelektas (DI) ir paskirstytosios operacijų knygos technologijos (DLT) suteikia konkrečių priemonių, kaip siekti aplinkosaugos, socialinių ir valdymo (ESG) tikslų logistikos organizacijose Baltijos šalyse. Aplinkosaugos pažanga akivaizdi Klaipėdos uoste, kur SGD bunkeriavimas, elektros energijos tiekimas sausumoje ir vandenilio iniciatyvos iliustruoja, kaip skaitmeninė stebėsena leistų mažinti išmetamųjų teršalų kiekį. Socialiniai ir valdymo iššūkiai, kuriuos iliustruoja „Vlantana Norge“ bylinėjimasis, atskleidžia nuolatinius darbo skaidrumo trūkumus, kai dirbtiniu intelektu pagrįstas anomalijų aptikimas ir blokų grandinės technologija apsaugoti įrašai galėtų pagerinti atitiktį reikalavimams. Valdymo inovacijos Rygoje ir Taline atskleidžia, kad privatūs 5G tinklai ir blokų grandinės bandomieji projektai sukuria audituojamo, tarpvalstybinio ESG ataskaitų teikimo infrastruktūrą. Tyrimo rezultatai atskleidė, kad Klaipėdos SGD bunkeriavimo, kranto elektros tiekimo (OPS) ir vandenilio projektai gerina aplinkosaugos rezultatus. „Vlantana Norge“ atvejis atskleidžia socialinės atsakomybės ir valdysenos atitikties rizikas, o Ryga ir Talinas demonstruoja valdysenos skaitmenizaciją diegdami 5G tinklus ir blokų grandinės (angl. *blockchain*) dokumentacijos sistemas. DI labiausiai padeda didinti efektyvumą ir užtikrinti rizikų valdymą, o DLT užtikrina ESG duomenų skaidrumą ir patikrinamumą. Abi technologijos veikia kaip viena kitą papildančios ESG atskaitomybės priemonės, nors platesnis jų diegimas priklauso nuo suderinamumo, sąveikos ir investicijų į skaitmeninę infrastruktūrą.

RAKTINIAI ŽODŽIAI: *aplinkosauga, socialiniai aspektai ir valdymas (ASV), dirbtinis intelektas (DI), paskirstytosios knygos technologija (DLT), blokų grandinė, logistika, tvarumas.*

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