Blockchain in Green Supply Chain Management: Comparative Legal Perspectives from Estonia and Georgia

Olha Prokopenko[1], Anzor Devadze[2], Badri Gechbaia [3]

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Abstract. This study investigates the application of blockchain technologies in the green SCM, with a specific emphasis on legal comparison between Estonia and Georgia. Blockchain has been evaluated as an efficient instrument for boosting supply chain transparency, augmenting corporate environmental responsibility, and increasing operational efficiency by better integrating data, mitigating the risks of fraud, and encouraging sustainability. The primary aim of this research is to analyse and compare the regulatory frameworks, practical implementation levels, and legal readiness for blockchain adoption in green SCM within Estonia and Georgia. This research draws on the dual approach of comparative law – analysing the existing regulatory mechanisms in both countries, studying the respective laws and policy documents, assessing the extent of practical application and consulting experts who are active in the development of green technologies and digital transformation. The results reveal that Estonia and Georgia are actively applying digital solutions for sustainable development. However, both countries have common problems such as a lack of clarity as to how blockchain can be used, a lack of common technical standards and insufficient digital infrastructure. But, at the same time, Estonia is more prepared from a legal perspective in terms of blockchain, mainly thanks to its e-governance systems. The theoretical contribution of this study is the possibility of supporting the establishment of more functional regulatory tools that promote the integration of blockchain technologies in green supply chains. This, in consequence, can contribute to the environmental targets and lower the eco footprint and business competitiveness. The findings are relevant for policymakers, lawyers, entrepreneurs and researchers working at the crossroads of digital technologies and sustainable development.

Keywords: blockchain, green supply chain, environmental management, legal regulation, Estonia, Georgia, sustainable development.

INTRODUCTION

Sustainability is a new aesthetic, and green supply chains have significance in sustainable development across the world. They want to minimise the harm to the environment primarily. Blockchain is an essential enabler of that effort. Blockchain is a critical enabler of that effort (Ansari, Khan & Zhang, 2019). This system offers transparency, real-time tracking of products, and adherence to environmental regulations (Wang et al., 2019). As blockchain is decentralised, it cuts down carbon emissions and streamlines logistics. (Beck et al., 2017). This is particularly crucial to champion green activities

[1] Olha Prokopenko
Doctor of Economics, Professor, Estonian Entrepreneurship University of Applied Sciences, Tallinn, Estonia, https://orcid.org/0000-0003-1362-478X
[2] Anzor Devadze
PhD in Economics, Professor, Head of Tourism Department, Batumi Shota Rustaveli State University, Batumi, Georgia, https://orcid.org/0000-0001-6344-7385
[3] Badri Gechbaia
Doctor of Economics, Professor, Head of the Department of Business Administration, Management and Marketing, Batumi Shota Rustaveli State University. Batumi, Georgia, https://orcid.org/0000-0003-2815-2228

in supply chains (Queiroz, Telles & Bonilla, 2019).

The two countries being Estonia and Georgia, are analysed in this research. Estonia is a pioneer and world leader in digital technologies and has been using the KSI blockchain in public services for many years. Georgia is, besides, currently working on blockchain applications, namely for real estate titles. Comparative studies show that Georgia faces more significant regulatory hurdles than Estonia as a smaller economy (Korchagina & Teodorescu, 2021). It is also comparative, for it allows examining how legal regulations on blockchain in green supply chains operate in several jurisdictions. However, although the significance of blockchain on sustainable development has increasingly attracted attention, research on the legal aspects of how blockchain is exploited in green supply chains is scant. Lack of standardised regulations is a significant barrier for Georgia, while Estonia benefits from EU-aligned blockchain standards (Frizzo-Barker et al., 2020). Primarily, there is a scarce comparison of legal environment of Estonia with the 2nd country, Georgia. It is therefore challenging to know which laws help the market to grow in using blockchain solutions for sustainable businesses and which ones are hurdles (Centobelli et al., 2022; Salah et al., 2019).

Based on the literature analysis and the identified research questions, a conceptual research framework was developed (Figure 1), which structures the approach to the comparative legal analysis of the implementation of blockchain technologies in the green supply chains of Estonia and Georgia.

Figure 1. Conceptual framework of the study: Blockchain in green supply chain management
Source: Esmaeilian et al. (2020)

Research aim

To conduct a comparative legal analysis of the regulatory frameworks of Estonia and Georgia regarding the application of blockchain technologies in green supply chains to identify factors that facilitate or hinder the successful implementation of these technologies to achieve sustainable development goals.

Research Focus

The study focuses on a comparative legal analysis of the regulation of blockchain technologies in green supply chains in Estonia and Georgia. Estonia exemplifies a country with a well-developed digital infrastructure and advanced e-governance systems, while Georgia illustrates the approach of a transitioning economy towards digital transformation.

The methodological focus is grounded in the principles of comparative law, adopting an interdisciplinary approach that integrates legal, technological, and environmental perspectives. Particular attention is given to identifying legal uncertainties, technological barriers, and institutional gaps in the regulation of blockchain for sustainable development.

The output focus is directed toward developing a conceptual framework for regulation and formulating practical recommendations to enhance national policies.

The findings hold international significance for countries facing similar challenges in implementing blockchain technologies within the context of environmental responsibility and sustainable development.

Research objectives and questions

The objective of this study is to contrast the legal systems of Estonia and Georgia concerning the application of blockchain technologies in green supply chains to determine the possibilities and barriers for the implementation thereof (Zhu, Geng & Lai, 2020). In this study, the following three issues are discussed:

What are the key features of the legal systems that govern blockchain in green supply chains in Estonia and Georgia?

How can these legal structures facilitate or frustrate the adoption of blockchains for sustainable development?

What can other countries learn from the two countries' experiences to better regulate blockchain in this context?

RESEARCH METHODOLOGY

Research Type

The approach to the research is comparative legal. This implies that the focus of the study is the examination of laws, guidelines, state policies and legal documents of Estonia and Georgia. Comparative studies show that Georgia faces more significant regulatory hurdles than Estonia as a smaller economy (Korchagina & Teodorescu, 2021). This perspective clarifies how these two nations govern the application of blockchain technology for the green supply chain. Lack of standardised regulations is a significant barrier for Georgia, while Estonia benefits from EU-aligned blockchain standards (Frizzo-Barker et al., 2020). It also helps us understand the commonalities, differences, opportunities, and barriers for implementing this technology. Estonia's legal conditions for the circular economy facilitate blockchain-based closed-loop supply chains more easily than in Georgia (Centobelli et al., 2022).

It uses both first-hand and other sources. Laws and regulations of the two countries are some of the main sources. These, particularly for Estonia, are the Digital Signatures Law, the Public Information Systems Law, the Cybersecurity Law and the strategic document "Digital Agenda of Estonia 2030". The decentralised nature of blockchain is better addressed in Estonian law, whereas Georgian legislation has yet to define clear provisions (Beck et al., 2017). In Georgia, the Law on Electronic Documents and Electronic Signature, the Law on Information Systems Protection, the Digital Governance Strategy, and certain materials related to the application of the blockchain technologies in the provision of public services, and definitions defined by regulatory acts such as the use of blockchain technology in the registration of real estate, are reviewed. Estonia has clearer jurisdictional solutions for blockchain-based cross-border trade than Georgia (Salah et al., 2019).

Secondary sources of information comprise scholarly articles and government reports and analytical reports of international organisations such as the OECD, the World Bank, and UNCTAD. International financial institutions emphasize blockchain's role in sustainable development goals (World Bank, 2021). These sources also include legal research into the regulation of blockchain, digital technologies and green supply chains. Blockchain technology can enhance transparency and traceability in green supply chains by securely recording environmental data across stakeholders (Ansari, Khan & Zhang, 2019). Blockchain improves tracking of sustainable raw materials from origin to consumer (Wang, Singgih, Wang & Rit, 2019).

The analysis is multi-level in the present study. First, the law is studied - its contents, structure, and the existence of certain norms regarding blockchain technologies and sustainable development. Estonia enables blockchain-based carbon trading through legal frameworks, whereas Georgia is only beginning to explore such regulations (Zhu, Geng & Lai, 2020). Secondly, it analyses how authorities organise work on digital technologies and who holds the competence to introduce environmental innovations. Blockchain adoption is driven by pressures for environmental compliance and consumer trust (Queiroz, Telles & Bonilla, 2019). Third,

practical examples of using blockchain in green supply chains are analysed to evaluate how the legal framework functions in the field. Estonia legally supports real-time emission monitoring through blockchain, while Georgia lacks specific regulations (Dutta et al., 2020).

The methodology of the study is a complex of analysis, synthesis, abstraction, induction, and deduction. Blockchain fosters sustainable supply chain practices through enhanced data sharing (Treiblmaier, 2018). This makes it possible to gather and analyse a huge dataflow and then to come to proven conclusions. A systemic method makes it possible to reflect not only the legal standards themselves, but also their interaction with technologies, as well as economic and sustainability needs. Developing countries may gain a competitive advantage by adopting blockchain-based sustainable supply chains early (Kshetri, 2018). Therefore, the selected method can provide a deep insight into how much the legislation of Estonia and Georgia is prepared for the introduction of blockchain solutions in green supply chains and what shall be improved to support environmental projects. Post-COVID supply chain resilience strategies increasingly incorporate blockchain solutions (van Hoek, 2021).

Data Sources

Blockchain has gained attention as an essential platform in support of sustainable supply chain management as well as the enablement of transparency, traceability and meeting environmental requirements (Esmaeilian et al., 2020). Studies also emphasise that blockchain supports fraud prevention and sustainability certifications by providing immutable records (Francisco & Swanson, 2018; Hackius & Petersen, 2017). Blockchain reduces carbon footprint and improves the efficiency of logistics processes, due to its decentralised character, which is particularly relevant for the implementation of environmental initiatives into SC (Asif & Gill, 2022; Thakker et al., 2024). Earlier research also highlights that permissionless and permissioned blockchain models have different impacts on energy efficiency (Kim & Laskowski, 2018; Nguyen, 2016).

Researchers also focus on security aspects and challenges of blockchain implementation, noting that appropriate technological and legal preconditions should be established (Longo et al., 2022; Shaikh, Al-Alawi, & Al-Busaidi, 2022). Blockchain interoperability and data privacy remain unresolved barriers in multi-tier green supply chains (Reyna et al., 2018; Salah et al., 2019). A comparative study of the legal systems indicates that the prospects for the use of a block for development are determined primarily by national policy, the stage of development of digital infrastructure and legal preparedness. As a leading country in e-governance, Estonia has a mature legal environment and is pushing forward with the KSI blockchain to innovate around this domain (Ambrozie & Sorcaru, 2023; Tatar, 2022). Scholars note that Estonia's leadership is tied to its strong digital identity and cybersecurity framework, which support blockchain integration (Mukkamala, Vatrapu & Hussain, 2020; van Hoek, 2021). Georgia's Digital Transformation Strategy emphasises the importance of blockchain integration in public services and economic sectors to improve transparency and efficiency. Georgia, on the contrary, is also deploying blockchain in the public sector, especially for real estate registration; however, legal vacuum issues have limited the deployment of the technology in green supply chains (Jovanovic et al., 2022; Korchagina & Teodorescu, 2021). International organisations underline that further legal alignment with EU standards could accelerate blockchain use in Georgia (Liu, Wang & Xu, 2021; World Bank, 2021). The literature emphasises the need to address challenges such as the absence of legal clarity, the absence of general standards, and the need for infrastructure to be able to fully exploit blockchain in SDGs (Ahmed, Streimikiene, & Balezentis, 2022; Kouhizadeh et al., 2021). Scholars argue that early adoption of blockchain-enabled sustainability policies can help developing countries gain a competitive advantage (Kshetri, 2018; Treiblmaier, 2018). Furthermore, the application of Blockchain with Internet of Things (IoT) and green logistics can potentially enhance the opportunities to optimise energy efficiency and environmental impact in multi-tier supply chains (Asif & Gill, 2022; Thakker et al., 2024). Other studies emphasise the potential of digital twins and advanced analytics when combined with blockchain to improve decision-making in sustainable logistics (Paliwal, Choudhary & Mathur, 2022; Perboli, Musso & Rosano, 2018).

The integration of blockchain with AI and IoT creates powerful synergies for achieving

supply chain sustainability (Saberi et al., 2019). Researchers note that such synergies are significant in monitoring environmental impact and circular economy practices (Chang, Chen & Lu, 2019; Dutta et al., 2020). Although blockchain's potential in sustainable supply chain has been widely acknowledged, there is a call for interdisciplinary research to synthesise legal, technological, and economic perspectives to craft harmonised policies and implementation frameworks in practice (Casino et al, 2019; Saberi et al., 2019). Some authors also highlight the need for better governance mechanisms and stakeholder collaboration to overcome current legal gaps (Hughes et al., 2019; Kaur & Singh, 2021). Policy frameworks must evolve to address both the opportunities and challenges posed by blockchain in sustainable logistics (Finck, 2019). This is particularly crucial for transition countries, where enhancing the legal environment can substantially speed up the uptake of blockchain-based solutions in green supply chains (Ahmed, Streimikiene, & Balezentis, 2022; Kouhizadeh & Sarkis, 2018; Zhu, Geng & Lai, 2020).

Table 1. Main directions, trends, and approaches to studying the blockchain issue

Main Directions	Trends	Approaches to Understanding the Problem
Blockchain Technology in Sustainable Supply Chains	Increasing adoption for transparency and traceability	Saberi et al. (2019) and Esmaeilian et al. (2020) emphasize blockchain's role in ensuring environmental compliance and supply chain transparency.
Legal and Regulatory Frameworks	Development of supportive legislation	Tatar (2022) and Ambrozie and Sorcaru (2023) analyze Estonia's advanced legal frameworks; Jovanovic et al. (2022) note regulatory gaps in Georgia.
Integration with IoT and Green Logistics	Enhancing energy efficiency and sustainability	Thakker et al. (2024) and Asif and Gill (2022) explore blockchain-IoT integration for improved environmental performance.
Overcoming Implementation Barriers	Addressing legal uncertainty and infrastructure challenges	Kouhizadeh et al. (2021) highlight the need to resolve regulatory gaps and infrastructure deficits.
Interdisciplinary Research Needs	Combining legal, technological, and economic perspectives	Casino, Dasaklis and Patsakis (2019) call for interdisciplinary approaches to policy harmonization and practical implementation.

Source: compiled by the author based on the analysis of scientific articles

Criteria for Comparison

This paper has chosen a few relevant criteria for comparing the legislation of Estonia and Georgia in the area of blockchain technologies in the green supply chains sector. The first one concerns estimating the degree to which the existing laws stimulate the blockchain and envision the legal conditions that are essential for implementing new mechanisms. The second criterion relates to the level of integration of environmental standards in the context of supply chains-regulation, i.e. whether these norms intend to promote sustainable development. Of substantial importance is the question of transparency and data protection in the context of blockchain technologies, which has an immediate impact on trust among market participants. We then also examined the question of which legal difficulties can arise or even prevent the introduction of blockchain solutions in this area.

Limitations

This research has some limitations. First, there is a lack of complete and up-to-date information on how blockchain is used in green supply chains in Georgia. Second, there are almost no open examples showing how the laws in this area work. Because of this, the analysis cannot be thorough, in-depth and comprehensive. However, the results of the study are still helpful and can help in further research and practical work.

RESULTS

Over the past decade, blockchain has greatly changed how the supply chain is managed, particularly in logistics. This technology has progressively embraced different applications since 2015. However, simple solutions for increasing transparency to complex systems are developed, which companies and institutions can track goods along the entire supply chain (Esmaeilian et al., 2020). Early adopters also highlight that pilot projects were initially used to test government involvement and legal frameworks for blockchain in logistics (Batubara, Ubacht & Janssen, 2018).

At first, those were all experimental projects, but blockchain became part of the real work in a range of sectors, food industry, pharmaceuticals, and manufacturing. The beauty of blockchain is transparency. All members have access to data in real-time. This would decrease the risk of fraud and mistakes. Blockchain enhances supply chain auditing by providing immutable transaction histories that improve certification processes (Francisco & Swanson, 2018).

Second, blockchain is also trustless, and has several advantages in a decentralised network, in which knowledge cannot be altered, which increases trust among the partners and helps in audit (Asif & Gill, 2022). The possibility to track the origin of goods also aids in the monitoring of quality and compliance with standards, which is particularly important in the current era, when special attention is given to the safety and environmental friendliness of goods. Blockchain improves data integrity in supply chains, reducing opportunities for greenwashing and false environmental claims (Chang et al., 2019). It also allows integration with IoT devices to validate sustainability metrics automatically (Bumblauskas et al., 2020).

As for the supply chain, blockchain contributes to the efficiency of operations, cost reduction and shorter delivery time for goods to arrive. With smart contracts, many of the procedures can be automated, and this reduces the chance of mistakes and causes the cooperation to be more efficient (Thakker et al., 2024). However, studies show that without standardised data-sharing rules, cross-border use of blockchain remains fragmented (Frizzo-Barker et al., 2020).

Yet, Blockchain has its hurdles. For example, scalability. For a few blockchains, a large number of transactions cannot be processed quickly, which in turn causes working with large global chains to be hard (Kouhizadeh et al., 2020). Energy consumption is another issue that is of utmost importance, particularly for networks that rely on the Proof of Work algorithm – a headache for ecologists. Recent studies also reveal that smaller economies struggle to meet sustainability goals when adopting energy-intensive blockchains (Centobelli et al., 2022).

Another challenge is the comparison and adaptation of blockchain technology with established systems like ERP, where there is no established standard to achieve such integration (Shaikh, Al-Alawi, & Al-Busaidi, 2022). Even if there's an ongoing interest in blockchain and supply chains, the legal aspects are being overlooked. No in-depth studies were found on laws, liability, data protection and standards concerning blockchain in logistics. It is the truth that obstructs the combination and development of the technology, which needs more experimental research in different areas, Ahmed, Streimikiene and Balezentis (2022). With the rise of awareness of transparency, traceability, and environmental responsibility in operating processes, the cooperation of blockchain technology has significant reference meaning in GSCM. Blockchain offers the foundational tools necessary to verify sustainability actions, decrease fraud in supply chains, quantify reporting and strengthen trust among supply chain partners. Experts also underline that collaboration among stakeholders is critical to overcome legal gaps and fragmented governance (Hughes et al., 2019; Kaur & Singh, 2021).

Efficient deployment of such solutions relies, among other factors, on legislative backing, the existence of national digitalisation plans and digital readiness. Comparison of the legal regimes of two countries: Estonia and Georgia. Through the prism of these two countries, we will ascertain how the legislative system can accelerate or impede the creation of innovative, sustainable supply chains. Estonia has long presented itself as a digital frontrunner with an advanced model of e-government, a high level of cybersecurity, openness to new technology and openness for new products and services. Blockchain adoption is supported by strong digital innovation ecosystems, which are a critical success factor for GSCM (Perboli, Musso & Rosano, 2018).

Moving from Georgia, this country shows a great appetite for digital evolution, but it is heavily challenged, especially as far as regulation

and mirror strategy are concerned (how does international convention fit into Georgia's local context?). To further explain the context of the specific features of a blockchain-based system's implementation in a country, a SWOT analysis of blockchain in two country cases – Estonia and Georgia was conducted. This approach allows both strength and weakness analysis and the opportunity and threat factors involved in the application of blockchain technology on the green supply chain.

The study is leveraged to highlight important factors that work in favour of or against technological development in each country and encourages the process of formulating suggestions for a more effective incorporation and implementation of blockchain technologies in the national domain. The results of the SWOT analysis on Estonia and Georgia and their legal, technical, economic, and social issues are summarised in a table below. The Global Innovation Index highlights that countries with higher digital maturity, like Estonia, tend to adopt blockchain faster for sustainability goals (WIPO, 2023).

GSCM is a concept that integrates green philosophy into the entire supply chain process. It encompasses design, supplier selection, production, logistics, distribution, product use, and disposal (Zhu et al., 2020). The primary goal of GSCM is to reduce the negative environmental impacts of a company's business practices, while also maximising resource efficiency and minimising ecological risks.

A fundamental part of this idea is the observance of environmental standards and certifications, which are generally such as ISO 14001 (Environmental Management System), EMAS (Eco-Management and Audit Scheme), FSC (Forest Stewardship Council certification), etc. Compliance with these standards obliges the companies to put in place transparent environmental processes and to audit the environmental impacts regularly (Testa et al., 2021). Blockchain can drive sustainable practices in the construction industry through material traceability and waste reduction (Perera et al., 2020).

But it is digitalisation that is now regarded as a core enabler to reach environmental objectives in supply chains. It increases transparency, provides source data traceability, facilitates information management, and promotes trust among all players involved (Saberi et al., 2019). In addition, digital technologies can automate action such as monitoring of emissions, effectiveness of environmental controls and carbon footprint generation, which is extremely critical. " This allows companies to react quickly to environmental challenges and respect international standards.

One of the fundamental concepts of GSCM is to move into the direction of a circular economy that optimizes the usage of resources, reduces waste, and uses recycled materials. This is an approach much related to 'environmental compliance'; businesses are no longer just applying the law, they are also innovating with an environmental perspective.

GSCM is also closely related to the achievement of the United Nations Sustainable Development Goals (SDGs) – in particular some goals including climate action (SDG 13), responsible consumption and production (SDG 12), affordable and clean energy (SDG 7), etc.

The Life Cycle Assessment (LCA) method is used to carry out an objective analysis of the environmental impacts with this project. LCA can be used for determining environmental impacts throughout the entire life of a product, from extraction of natural resources to waste disposal.

Against this extensive background of use of GSCM in practice, less well understood is the role of national legislation in spurring digital technology adoption to achieve environmental outcomes, including blockchain. There needs to be more scientific evidence to describe how laws and systems could be better shaped to allow blockchain technology to be implementable and readable when it comes to transparent use, emission monitoring, and environmental compliance (Ahmed et al., 2022; Kouhizadeh et al., 2021).

This area needs more interdisciplinary studies that draw on legal, technological, and environmental theories to inform viable, sustainable development solutions.

Table 2. SWOT analysis of blockchain system implementation in green supply chains (Estonia vs Georgia)

Category	Estonia	Georgia
Strengths	- High level of digitalization and IT infrastructure - Clear blockchain legislation - Leadership in digital governance (e-Residency) - High trust in digital services - Integration with other technologies (IoT, AI)	- Openness to digital innovations - Basic IT competencies - Strategic location as a transit hub - Support from international organizations
Weaknesses	- Small domestic market - Need for legislative updates - Insufficient number of qualified specialists	- Lack of comprehensive legal regulation - Underdeveloped digital infrastructure - Limited access to financing - Low digital literacy and trust
Opportunities	- Development of green supply chains - Expansion of international cooperation - Attraction of investments in high-tech projects - Increasing transparency of business processes	- Development of regulatory acts - Cooperation with international partners - Use of blockchain to fight corruption - Growth in fast-developing sectors (agro-industry)
Threats	- Cyber threats - Overregulation - Competition with other countries - Social inequality in access to digital services	- Lack of clear policy - Political instability - Weak cybersecurity - Low trust in institutions

Source: created by the author based on Global Innovation Index (2023), Tatar (2022), and Ahmed et al. (2022).

The results Table 3 of the temporal analysis results indicates significant differences in the speed and nature of the digital transformation of the two countries, which confirms the hypothesis of the crucial role of national digital development strategies and the legal environment in the processes of implementing innovative technologies to achieve sustainable development goals.

Table 3. Evolution and Development Prospects of Blockchain Technologies in Green Supply Chains: Estonia vs Georgia

Period	Development Indicator	Estonia (%)	Georgia (%)	Comments
2015-2017: First Experiments	Digital Readiness	85%	25%	Estonia: KSI blockchain launched in 2012, X-Road platform operational since 2001. Georgia: beginning of digital reforms, launch of blockchain land registry in 2016
	Legal Framework	70%	15%	Estonia: basic legislation for digital signatures developed. Georgia: fragmented regulation without systematic approach
2018-2020: Practical Implementation	Blockchain Infrastructure	80%	35%	Estonia: KSI expansion to all state registries, e-Residency reaches 50,000 users. Georgia: successful land registry operation, first international recognition
	Cybersecurity	90%	40%	Estonia: NATO CCDCOE establishment, top-5 in global cybersecurity ranking. Georgia:

				development of basic protection systems
2021-2023: Integration with IoT and AI	Technological Integration	75%	30%	Estonia: IoT + blockchain pilot projects in logistics, integration with EU digital initiatives. Georgia: limited experiments, focus on basic digitalization
	Environmental Integration	50%	20%	Estonia: participation in EU Green Deal, beginning of environmental monitoring. Georgia: minimal environmental initiatives
2024-2025: Current Stage	Overall Readiness	85%	45%	Estonia: leadership in digital governance (3rd place UN EGDI 2022). Georgia: Digital Strategy 2021-2025 under implementation
	Green Supply Chains	60%	15%	Estonia: limited practical projects, strong theoretical foundation. Georgia: absence of specialized projects
2026-2028: Mass Implementation (forecast)	Process Automation	90%	60%	Estonia: expected full smart contract integration in public sector. Georgia: expansion of digital services, international support
	Environmental Monitoring	80%	40%	Estonia: automatic carbon footprint tracking. Georgia: implementation of basic environmental control systems
2029-2030: Global Ecosystem (forecast)	International Integration	95%	70%	Estonia: leadership in EU blockchain standards. Georgia: integration with European systems
	Sustainable Development	90%	60%	Estonia: full integration with UN SDGs. Georgia: significant progress in achieving environmental goals

Source: created by the author based on Global Innovation Index (2023), Tatar (2022), UN E-Government Survey 2022, and Estonia's Digital Agenda 2030.

The country boasts an advanced digital infrastructure and liberal legal framework for e-governance, setting the stage for the adoption of blockchain technology. The potential for technological integration increases with the degree of public sector support for digitalisation and citizens' trust in online service delivery. And, Georgia feels no pain with its easy-to-regulate legislative regulations and firm resolve to be business-friendly with technological savvy that fosters inventiveness. Low entry barriers and private sector participation are also favourable to blockchain initiatives.

Notwithstanding its successes, Estonia is still confronted with security risks and the necessity of a never-ending modernisation of its legislation to stay aligned with continuously maturing technological standards. Elsewhere, a lack of sufficient government support and a regulatory environment for blockchain technology in Georgia hamper its widespread integration. There is a low level of digital literacy in the population and little trust in new technologies, which also delays progress in this field.

Both Estonia and Georgia show high institutional capabilities for the implementation of blockchain technology in green supply chains, particularly in the energy, agriculture, and logistics sectors. Estonia has the advantage of being part of the European Union, which increases its access to global markets, partnerships and funding. At the same time, Georgia's bridge position between Europe and Asia allows the development of cross-border blockchain systems and attracts investment by creating technology zones and innovation centres.

There are significant challenges for both Estonia and Georgia in integrating blockchain technology, not least the rapidly changing tech environment that can cause existing systems to become obsolete. In Estonia, the most significant threats are cybersecurity and risks of possible cyberattacks. If data and privacy are not secure enough, trust can be compromised. On the contrary, political instability in Georgia and

the ambiguous regulatory market of blockchain might restrict foreign investments in the country as well as its global interaction. Moreover, both nations suffer from skill shortages needed to sustain and grow advanced digital ecosystems. The SWOT analysis conducted reveals that the sophistication of the digital infrastructure significantly determines the success of the adoption of blockchain technology in these countries, the availability of a progressive regulatory environment and the acceptance of technology by the people. Estonia has a pro-active government policy, high levels of digital literacy among citizens and close integration with EU organisations, all of which place the country in a strong position for large-scale application of blockchain in sustainable supply chains. Georgia's strengths are its flexible legislature and good geographical location, but poor regulation and a lack of solved cybersecurity problems hinder development. Common risks between the two nations are, for example, the need to keep pace with fast-moving technology trends and the struggle of educating a workforce needed to maintain blockchain-based systems. Focus on strengthening cybersecurity measures and clarifying legal norms to increase stakeholder trust and foster the implementation of blockchain-based solutions.

A comparison between Estonia and Georgia in terms of legal provisions managing the use of blockchain technologies for the green supply chain also highlights essential differences in their regulatory approach. Estonia is a frontrunner in terms of digitalisation and e-government, which would create an enabling environment for the deployment of emerging technologies, like the blockchain. Estonia's digital infrastructure, based on interoperable public services and blockchain, sets an example for sustainable governance (Ministry of Economic Affairs and Communications, Estonia, 2020). It has a more evolved legal ecosystem that has well-developed e-gov, cybersecurity and data privacy laws to support the digital infrastructure growth. More broadly, some policy initiatives aim at fostering environmental innovation, which might make room for blockchain and sustainable supply chain practices. Yet, the absence of legislation on blockchain's application to environmental matters in the law suggests that it is required to enhance regulations to capture the blockchain technology. Estonia's legal and digital infrastructure facilitates the implementation of blockchain in public services, enhancing trust and sustainability outcomes (Tatar, 2022). In contrast, although Georgia has made significant progress in implementing blockchain in its public sector operations – most notably its land and property registry records— regulation to support its application in green supply chains is underdeveloped and fragmented. Georgia's experience in blockchain-based land registry demonstrates transparency improvements but also highlights regulatory gaps.

Existing legislation primarily focuses on the development of the digital economy and broad e-governance programmes, rather than directly targeting sustainability or environmental integration. Both pointed to the lack of an integrated legal background between digital innovation and environmental policies, proposing the strengthening of regulatory foundations urgently. Such developments would allow the safe and efficient implementation of blockchain technology for environmentally responsive logistics and supply chain systems. Smart contracts on blockchain facilitate automatic compliance with environmental regulations in supply chains (Queiroz, Telles & Bonilla, 2019). To analyse the legal regulation of the application of blockchain technology in green supply chains in Estonia and Georgia, a systematic comparison was conducted according to the selected criteria. These are the legal context, the inclusion of environmental norms, the levels of transparency and data protection, the existence of legal obstacles, and the practice of some concrete cases. Blockchain catalyses increasing transparency in food supply chains, ensuring ethical sourcing and minimising waste. Adopting blockchain improves circular economy practices by facilitating material traceability and end-of-life product management (Upadhyay et al., 2021). Once compared in such a structured manner, both main trends and particularities of each country are revealed, and the factors that either drive or limit the successful application of blockchain towards making supply chains sustainable become evident. Blockchain-based systems enable better verification of sustainability certifications within the supply chain (Cole, Stevenson, & Aitken, 2019). Estonia, which is one of the World's most advanced digital societies, has a mature legal backdrop enabling the use of next-generation technologies such as KSI Blockchain and digital identity infrastructure in general. Such regulations provide a positive environment for

incorporating environmental factors into supply chain and logistics systems, which results in transparency and a cut in CO2 emissions. Georgia, however, is still in the early process of creating regulatory frameworks for blockchain, primarily focused on individual government projects. This lack of generalisation limits the application of the technology to environmentally motivated areas. The comparison across two countries highlights the importance of regulatory barriers and the dearth of thorough policies in determining the extent and rate of the adoption of blockchain in green supply chain practices.

Table 4 below presents the key characteristics of the legal regulation of blockchain in green supply chains in both countries according to the mentioned criteria.

Table 4. Comparative analysis of legal regulation for the implementation of blockchain technologies in green supply chains: Estonia and Georgia

Comparison criteria	Estonia	Georgia
Legal framework for blockchain	Developed, includes KSI Blockchain and digital identity legislation	In development, focused on blockchain in public services (e.g., land registration)
Integration of environmental standards	Partial integration, supports sustainability through digitalization	Limited integration, lack of systematic regulation in the environmental domain
Transparency and data protection	High level due to KSI technology and digital identity	Insufficiently regulated, risks due to legislative gaps
Legal barriers to implementation	Minimal, supported by the government	Bureaucratic and regulatory obstacles exist
Examples of application in green supply chains	Initiatives in logistics and carbon footprint reduction, but still limited	Absent or minor examples of application in green supply chains

Source: systematised independently by the author

Legal bases for digital technologies in Estonia and Georgia substantially affect the integration of blockchain for sustainable development. Low-level Estonian legislation is highly conducive to the digital environment and includes the infrastructure to facilitate 'e-governance', e-identification and data protection by default. A combination of government incentives and regulatory clarity accelerates blockchain deployment in sustainable supply chains (Tatar, 2022). We have a digital infrastructure across the whole of Estonia — with better environmental regulation than in the US (since we are part of the EU) — and that's an excellent basis for implementing blockchain in a green way." This involves validating ecological footprints, certifying products and controlling emissions. But the lack of dedicated legislation directly targeting environmental issues regarding blockchain will prevent its complete implementation in the sustainability field. Georgia is not a case similar to Ukraine, where the legal uncertainty and environmental requirements' ignorance is a successful use of blockchain technology application in green supply chains, despite good practice in the application of this technology in the public sector. Decentralised legislation and a lack of online website auditing tools limit the application of blockchain for sustainable management. Decentralised blockchain networks reduce reliance on third parties while enhancing the environmental performance of supply chains (Pournader et al., 2020). Consequently, while the enabling legal structure of both nations partially encourages overall digital developments, environmentally friendly blockchain use still needs a legitimate definition, along with an interdepartmental dialogue. By comparing how Estonia and Georgia have approached the regulation of blockchain technologies in green supply chains, we have identified some important learning points that may guide the development of national and supranational regulation. Estonia's example demonstrates the power of matching digital transformation with legal certainty and institutional support for innovation. These very building blocks are necessary to successfully embed blockchain into different sectors, even potentially environmentally conscious ones. More specifically, the state's commitment to

maintaining a hand in digital infrastructure and following suit when it comes to EU standards ensures that the country has a relatively stable regulatory environment, which could be looked at as a model for those countries that are yet to develop their digital systems to such an extent. The Georgian treatment, on the other hand, emphasises the need for diversity in technology adoption, even in the presence of some legal uncertainty, leaving the field open for experimentation and piloting. But the absence of clearly formulated environmental goals in Georgia's digital policy indicates that cross-sectoral coherence in regulatory approaches is necessary. It comprises the elaboration of shared standards, interstate collaboration and institutional impetus to be extended to the use of blockchain technology in the area of sustainable development.

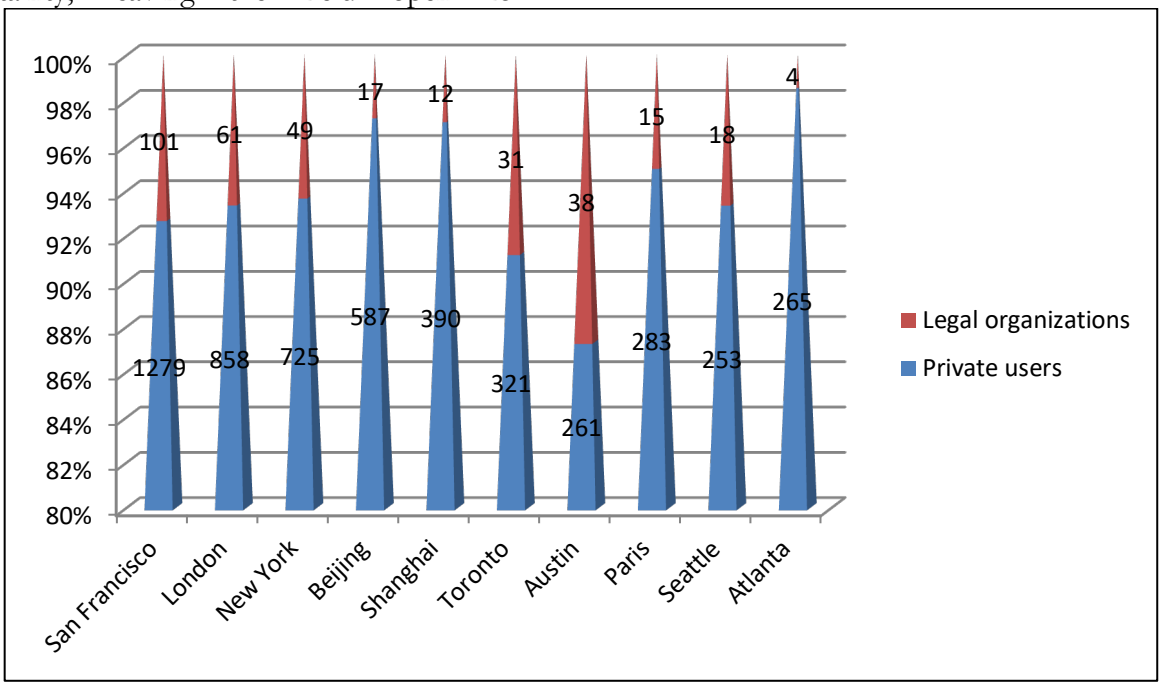

Figure 2. The largest cities in the world are actively developing blockchain technologies

In the modern era of the digital economy, solutions built with the help of blockchain technologies continually draw the interest not only of businesses, but also of authorities in different countries. Legislation on data protection in the context of IoT is heterogeneous and fragmented in nature, with approaches to rule-making on the matter being very diverse between different jurisdictions. On the other hand, blockchain provides plenty of opportunities to improve transparency, trust and efficiency, especially for green supply chains. On the other hand, it poses great practical and legal issues regarding data protection, legal validity of the records, and the liability sharing on decentralised networks. Regulation of blockchain technology: EU approach. The European Union presents perhaps the most comprehensive regulation of blockchain. The EU wants to create legal certainty for those in the field and users of blockchain solutions by making the development of the European Blockchain Services Infrastructure (EBSI) an enabler of the European Blockchain Partnership (EBP). The approval of MiCA was a crucial move towards setting common rules for the circulation of crypto-assets and related technology. Moreover, the Digital Services Act (DSA) tightens rules for safeguards such as data protection, security & accountability of platforms deploying distributed ledger technologies. At the same time, the legal system of the EU is confronted with a number of difficult challenges. One of the important things is to ensure GDPR compliance in blockchain operations. In particular, the right to erasure ('right to be forgotten') is provided in Article 17 of the GDPR, whereas the core of the blockchain is that all transactions are irreversible. This conceptually conflicts with the right to be forgotten with blockchain technology, where deletion of information from blockchain is technically impossible. In this article, academics and practitioners suggest several solutions to the problem, among which are off-chain storage, hashing, and pseudonymisation.

The US, however, employs a piecemeal legal approach to blockchain. On the ground,

the picture is predominantly state-driven, with most legislative efforts focused at the state level. Wyoming, for instance, was one of the first states to confer legal recognition to blockchain-represented records and to implement a regulatory framework for Decentralised Autonomous Organisations (DAOs). Yet the lack of a federal statute means that there is continued uncertainty and lack of clarity, especially with respect to liability, customer protection and broader regulation of the blockchain field. In contrast, outside of China, the regulatory landscape in Asia is more aligned, with countries like Singapore, Japan showing a homogenous regulatory approach. Their regulators actively promote technology innovation through clear, albeit reasonably flexible, rules. Japan has been one of the top countries embracing cryptocurrencies as legitimate forms of payment, and the country's financial regulating body, the Financial Services Agency (FSA), has strong but clear control of financial technologies, though Japan's current lack of regulations has encouraged more blockchain technologies to join forces. Likewise, in Singapore, there is a regulatory sandbox set up to test-drive imaginative blockchain solutions without fearing the violation of the law, apart from tax rebates available to tech start-ups. Despite numerous attempts to regulate, we face multiple legal battles without a global resolution. Maintaining the validity of blockchain records, especially in the light of GDPR and the distribution of the responsibility between the different entities of a decentralised network, is among other issues particularly challenging the blockchain legal sector, as well as the resolution of cross-border legal conflicts and the setup of Common Reference Identifiers for different blockchain systems.

Therefore, according to international experience, the effective legal regulation of blockchain technologies should combine the protection of users' rights, information security and the encouragement of innovative activity. It is also necessary to take into account the specifics of each country, or the degree of digital maturity of the country, as well as its strategic interests in sustainable development and digital transition. However, there is currently no one legal measure that addresses all facets of blockchain application, especially when it comes to its application as a tool for attaining environmental objectives such as the development of green supply chains.

Insights from cities that have emerged as the top adopters of blockchain technology are important to understand the context under which this revolutionary technology might be best integrated in the green supply chain ecosystem. Indeed, this analysis yields that blockchain will never take hold successfully unless a specific combination of factors is in place: stable legal regulation; a high level of digitalisation of public services, incentives for the private sector, and local authorities with a strategic vision of digital transformation. Such conditions form a positive background for the introduction of blockchain in logistics, the power industry, agribusiness, and other areas where the industries are directly connected to supply chains. In this regard, there are examples of cities, such as Singapore, Tallinn, Dubai and Toronto, where government policy is shaping through entrepreneurial innovation, the green efficiency of their digitalised world. For example, Singapore, due to the institutional support of technological innovation, established special pilot zones where blockchain technologies have been tried out at real economic scales. In the same vein, Tallinn's experiences have demonstrated the potential of public digital infrastructure to guarantee transparency and reliability along the entire supply chain spanning from the producer to the end consumer.

Estonia has been termed a world leader in digitalisation. The country's digital transformation began shortly after independence in 1991, with its proclamation of a grand vision to bring about an efficient and transparent state driven by digital technologies. In 2001, Estonia established X-Road, a decentralised system for secure data exchange among public and private organisations. This structure started e-Governance, in which 99% of government services are available to citizens and businesses online. Estonia's National Digital Agenda (2020) outlines the country's commitment to integrating blockchain in government and environmental monitoring systems (Ministry of Economic Affairs and Communications, Estonia, 2020).

Keyless Signature Infrastructure (KSI) blockchain technology is a fundamental part of the cybersecurity framework that protects Estonia´s digital ecosystem. KSI was developed in the mid-2010s in partnership with the Estonian company Guardtime and is not a classical blockchain as known from cryptocurrencies, but a system based on hashing

and creating timestamps. It also guarantees the non-changeability of data in registries. On legal grounds, KSI certifies the evidence value of digital records, which is a vital factor for the integrity and trust of information in government registries and transactions.

A major step towards Estonia's digital society was reached in 2014, when the eResidency program was started. Through the programme, foreign nationals can become digital residents of Estonia, and they can access the e-services of the government remotely, set up companies, sign documents, and pay taxes. This programme has its legal basis in the Electronic Identity and Trust Services Regulation, which is under the acquis of the EU, especially the eIDAS Regulation.

The strategic paper determining the development direction of the Estonian digital state in the next decade is called the Digital Agenda Estonia 2030. This initiative is planned to include more AI, digital infrastructure, and cybersecurity, and to automate all government services fully. Particular focus is placed on digital solutions for sustainable development. Nevertheless, the application of blockchain in green supply chain management is unexplored, on both academic and industry fronts.

The credibility of digital services was a significant concern in Estonia. The cybersecurity system depends on decentralised decision-making, cryptography, and continuous auditing, all designed to provide a robust level of protection for citizen and business data. Furthermore, the KSI blockchain is a crucial component of this system, ensuring the immutability and integrity of digital transactions even in the face of cyber threats.

Despite the considerable advancement in the digital transformation, we should emphasise that the real-world implementation of the blockchain solutions of Estonia in the management of green supply chains has not advanced so far. Current studies are mainly devoted to digital public services, cybersecurity, and administrative processes. Meanwhile, the possibilities of incorporating such tools into environmental management systems (for instance, monitoring carbon footprints, accrediting environmental standards, and improving the transparency of sustainable production chains) would also need to be further investigated.

Georgia is one of the examples of a transition economy, where digital technologies, including blockchain, have been adopted in public administration and other areas of the country's economy. The main planning document for the country's digital transformation is Georgia's Digital Transformation Strategy 2021–2025, formulated by the government with the participation of international organisations such as USAID and EU4Digital. The plan aims to create digital skills for the entire population, digitally modernising the country's infrastructure and incorporating tech like AI, blockchain and cloud computing in both public administration and businesses.

One of the earliest, best-known projects where blockchain was applied in Georgia is the real estate registration, which was implemented in the country in cooperation with Bitfury in 2016. This option allows transactions that transfer the property to be recorded on the blockchain, facilitating immutable data with transparency and fraud protection. The Georgian experiment is considered one of the first instances in the world of blockchain being applied to public registries.

The legal system in Georgia conforms to the transition type. For one, it is actively bringing its laws in line with European norms, signalling interest in piercing the European digital single market. Conversely, structural obstacles have not been removed, and the unsound legal environment for new technologies, like blockchain, is still evident. Most of the law regulations are based on the applied flexible instruments coming from general law sources, which allows wide interpretation but at the same time causes some legal doubts.

A remarkable feature of the digital policy in Georgia has been the introduction of regulatory sandboxes – where innovative new solutions can be tested in a controlled legal environment prior to rolling them out more widely. This is especially important for fintech and blockchain startups, since it facilitates a joint evaluation with developers and regulators about the risks and the benefits of these new products.

And Georgia is proactively moving forward with laws intended to promote investment in IT, including tax breaks for technology companies and startups. Early-stage companies, like start-ups, have room to prosper and develop here, and this is an ideal climate conducive to developing digital tech such as blockchain. In the international legal regime, we must note the principle of the prevalence of international treaties over national legislation,

which is conducive to the integration of Georgia into global legal and digital processes.

Although limited successes have been made towards the implementation of blockchain applications in the public sector, it is worth mentioning that the use of this technology in the context of green supply chains and environmental management in Georgia is barely examined. In the national context, little academic research is being conducted to comprehensively study how blockchain can contribute to the national sustainable development goals. This gap indicates a significant need for cross-disciplinary research bringing together legal, technological and environmental perspectives on Georgia's digitalisation.

The role of blockchain technology in greening supply chains is being considered as an emerging and increasingly significant means to improve the transparency, traceability, and environmental accountability of business operations (Esmaeilian et al., 2020). But despite its enormous potential, various technological, legal, and economic hurdles in place are preventing the creation of sustainable digital solutions in logistics using blockchain technology. Researchers Kouhizadeh et al., (2021), Saberi et al. (2020), Sarkis, & Elmorghni (2020), United Nations Development Programme (UNDP), Ullah et al. (2020), Thakker, Rane, and Narwane (2024) highlight the global environmental challenge in blockchain technology, particularly with of high levels of energy consumption from specific consensus mechanisms such as Proof-of-Work, that also contradict the aspirational objectives set by the United Nations Sustainable Development Goals. On the other hand, the worldwide shift to energy-efficient mechanisms like PoS and PoA is far from being fully implemented because of technical and regulatory constraints. The Twists and Turns are Just Beginning on Distributed, Blockchain Enterprise Technology. Another major challenge is the difficulty of hooking up blockchain with ERP. Lack of a standard protocol and interoperable data exchange standards hinders the collaboration among different supply chain partners, as Asif and Gill 2022 and Ahmed et al. (2022). The interoperability challenge is still among the key factors that have been slowing down the massive adoption of blockchain in the logistics sector. Legal Barriers Legal barriers are also of utmost significance, being primarily associated with the uncertainty over the legal value of blockchain records. As Finck (2019) notes, in many jurisdictions, there is an open question regarding whether and when data recorded in blockchains would be admitted as evidence in court or in a commercial dispute. Moreover, insurmountable legal contradictions exist between the unchangeable principle of blockchain data and the legal assumptions of the GDPR, in particular, the principle of the right to be forgotten. This poses serious challenges for the adoption of blockchain technologies in regulated sectors such as those that handle personal or commercially sensitive information (Shaikh, Al-Alawi, & Al-Busaidi, 2022).

There are also other significant legal obstacles known as cross-border operations. Lack of harmonised international regulation. Lack of convergence of international regulation may cause legal disputes when blockchain networks cross borders and may involve questions related to liability distribution and the legal status of electronic records. The cost of entry to building and deploying blockchain-based solutions is the most substantial barrier to entry. As per the studies by Kouhizadeh et al. (2021) and Ahmed et al. (2022), the cost-benefit of adopting blockchain technology is challenging for the organisation to determine, mainly in the short run. For numerous green technologies, the ROI of the private sector is unclear, which prevents significant investment of market in those technologies.

Meanwhile, the government endorsement is also a significant factor when it comes to blockchain adoption. Disruptive leverage mechanisms such as regulatory sandboxes, tax relief, investment funds for digital environmental solutions and preferential conditions for IT companies are important. As shown by the experience of different countries (Tatar, 2022; Thakker et al., 2024), the synergy between a clear legal framework and economic incentives has a positive effect on the process of integration of blockchain technology with corporate sustainability strategies.

This diagnostic must incorporate key evidence, including the level of digital maturity, the public budget allocated, the legal protection of data, the level of involvement of citizens and the mechanism of public and private co-operation. Particular focus might be given to the examination of public-private partnerships, the key to a strong innovation ecosystem. Looking into such efforts — whether among cities such

as Dubai and San Francisco — can provide valuable insights into current models of collaboration, and the barriers that have kept them from scaling up. So it is interesting to contrast results of different cities or countries, not only to contribute to the academic discovery of what is going on in terms of digitalisation in the environmental sphere, but to provide concrete entry points for sustainability policy that integrate global requirements with local potentials. It's a model that's particularly well suited for digital transitioning countries like Georgia – it can emulate what's working in "best in class" innovation hubs, and build on it in a way that's appropriate to its stage of development.

Results reveal diverging principles of legal regulation of blockchain in green supply chains within both Estonia and Georgia. Estonia illustrates a holistic and proactive framework, including explicit legal rules and a technological environment that would make it easier for creative solutions to be put into practice in the field of sustainable development. On the other hand, despite the public sector's proactive efforts, Georgia is dealing with some lack of regulatory clarity and bureaucratic hurdles. This gap determines the diverse readiness between both countries regarding the mass adoption of blockchain in green supply chains. The preconditions for connecting environmental requirements with digital by default exist in Estonia, and a platform is provided for the development of mitigating negative environmental effects. Conversely, Georgia must also work on its legal system that would regulate not only the legal status of blockchain solutions, but also the peculiarities of environmental regulation in the supply chain territory.

DISCUSSION

Interpretation of Results

The utilisation of blockchain technologies within green supply chains is becoming increasingly more interesting as a means to increase transparency, traceability and environmental accountability in business (Esmaeilian et al., 2020). Yet even with its great promise, various technical, legal and financial challenges could prevent broader use of blockchain and sustainable digital concepts in logistics. At the technological level, high energy costs of some consensus mechanisms, in particular, e.g. PoW, are listed as key challenges in literature (Kouhizadeh et al., 2021; Thakker et al., 2024) and are not in line with the goals of sustainable development. Meanwhile, the planet-wide switch to less energy-intensive means – such as Proof-of-Stake or Proof-of-Authority – is hampered by technical and regulatory bottlenecks. Another important barrier is the difficulty of interoperating these blockchain platforms and existing enterprise resource planning (ERP) systems. A unified standard protocol and standard data exchange consideration is not yet available, leading to the complex collaboration among different players in the supply chain from Asif and Gill (2022) and Ahmed et al. (2022). The lack of interoperability remains one of the leading barriers preventing the broad-based implementation of blockchain in the logistics sector. Legal barriers are just as essential and are primarily due to the unclear legal status of blockchain entries. Indeed, whether information in blockchain records is recognised as formal proof in court and in disputes between commercial parties still depends on the legal system (Finck 2019). Moreover, there are substantial legal tensions regarding the principle of immutability of blockchain records and the fact that the EU GDPR - particularly the right to be forgotten - applies to the data embedded in the blockchain. This presents a significant impediment to the implementation of blockchain solutions in regulated domains where personal or commercially sensitive data is involved (Longo et al., 2022; Shaikh, Al-Alawi, & Al-Busaidi, 2022).

Another significant legal challenge relates to the conduct of cross-border activities. Lack of internationally harmonised governmental regulation creates legal disputes and litigation when blockchain networks cross international boundaries and the infrastructures of various applicable sovereigns follow varying models for protecting personal data, allocating liability, and providing legal recognition for digital records. The economic obstacles are mainly associated with the considerable upfront cost to develop and deploy blockchain applications. As studied

by Kouhizadeh et al. (2021) and Ahmed et al. (2022), many firms find it difficult to estimate the costs and benefits of blockchain adoption, especially in the short term. The ROI is not clear on most green solutions, so the private industry is reluctant to make major investments in green technologies.

Meanwhile, supportive policies are a significant engine for the promotion of blockchain applications. Regulatory sandboxes, tax incentives, investment funds for digital environmental solutions, and preferential conditions for IT companies are crucial mechanisms to this effect. The coexistence of a solid legal framework with economic incentives, as the experience of some jurisdictions shows (Tatar, 2022; Thakker et al., 2024), allows the bend of the adoption curve and the introduction of blockchain in company sustainability strategies. It can be concluded that to apply blockchain technologies in green supply chains, the technological limitations must be solved, the legal uncertainties must be overcome, and the economic viability of the business must be guaranteed.

Comparison with Literature

The findings of this study are consistent with prior research that underscores the critical role of a supportive regulatory framework in the effective implementation of blockchain within sustainable supply chain systems (Esmaeilian et al., 2020; Kouhizadeh et al., 2021). For example, Ambrozie and Sorcaru (2023) posit that blockchain adoption can be fast-tracked in countries with robust legal systems, especially in the context of environmental transparency and resource flow tracking. Similarly, Longo et al. report that pilot blockchain initiatives are relatively successful in regions where there is clarity in the legal framework. Thakker et al. (2024) also indicate that the deployment of blockchain-IoT for GSC is much more effective when it is underpinned by strong regulatory support, as technology alone in this context tends to be weak.

Limitations

This research has certain limitations. First, the lack of access to complete legal and statistical materials about Georgia hindered a more detailed analysis of the impact on regulatory matters. This limitation is consistent with the results of Shaikh, Al-Alawi, and Al-Busaidi (2022), which underscore the degree to which the limited availability of open data constrains the ability to fully evaluate the effectiveness of blockchain in the context of less digitally transformed countries. Secondly, technical and institutional aspects, namely, the level of the digital skill of enterprises and infrastructure constraints, were not deeply discussed, which may influence the generalizability of findings (Korchagina & Teodorescu, 2021). Furthermore, it is to be recognised that the dominance of English references may not necessarily capture the context of local regulation.

Implications

The findings in the study are highly relevant for policymakers and industry stakeholders. They suggest that governments that consider promoting blockchain adoption in the context of their green supply chains would need first to establish comprehensive legal frameworks to support digital innovation and environmentally-related information transparency (Casino, Dasaklis & Patsakis, 2019). For companies, it can create a competitive edge to be able to accommodate existing or new regulations in an increasingly environmentally conscious world. Academic investigation might be oriented towards more comprehensive comparative research among countries and the construction of models designed to maximise the exploitation of the technology offered by specific legal frameworks (Jovanovic et al., 2022). Similarly, the combination of blockchain with some technologies (e.g., IoT,Thakker et al., 2024) is allowing new possibilities for the more efficient green supply chain management.

CONCLUSIONS

The comparative study of legal regulation of blockchain technologies in green supply chains of Estonia and Georgia allows us to conclude, the quality of state regulation largely determines the efficiency and urgency of these processes. More specifically, the legal and regulatory framework offered by Estonia, based on tenets of digital transparency, data authenticity and legal recognition of records managed through a blockchain, is serving as a driver for the adoption of blockchain-based systems in supply chains with a focus on

sustainability. The existence of legal frameworks, e-identity, digital signatures and even the use of blockchain in public registries facilitates not only the implementation but also the trust between supply chain actors. This responds directly to the research question of how legislation affects the practical application of blockchain for environmental purposes.

On the contrary, in Georgia, there is a lack of speculative regulations; regulation is not normalised in connection with the use of blockchain, nor are legal regulations regarding the protection of data, the possibility of executing smart contracts, or the allocation of liability in decentralised networks. These lacunae are, however, responsible for an impasse in the spread of blockchain technology in sustainable supply chains, with a narrow scalability potential and low environmental effectiveness. This supports the second research hypothesis of a lack of legal support as the main obstacle to blockchain adoption in destinations at lower levels of digital transformation.

In addition, Georgia's regulatory gaps are a result not just of a lack of lawmaking precision, but also of underlying systemic challenges in its strategy for digital transformation. That comes to show that the implementation of blockchain in the green supply chains is not merely a technical problem but essentially a legal and institutional one.

A further important limitation observed in that review – there is a pressing need for detailed analysis of, for instance, blockchain applications in certain sectors, or private law implications of intermediaries operating on the blockchain in various jurisdictions. In so doing, such research should consider sectoral needs, local legal constraints and cross-sectoral problems. Absence of such information has so far prevented policymakers from developing robust legal frameworks that encourage innovation, respond to global trade and consider the environment.

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