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Sustainability in Global Value Chains: The Role of Digital Innovation and Blockchain

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Preface

Writing this thesis has been a truly meaningful and transformative experience that allowed me to combine my interests in innovation, sustainability, and technology. Exploring how blockchain can contribute to more transparent and responsible global value chains has deepened my understanding of both the challenges and the opportunities of sustainable business transformation.

I would like to express my sincere gratitude to Univ.-Prof. Aveed Raha, PhD, for his valuable guidance, constructive feedback, and continuous support throughout this research. His insights and encouragement have been essential in shaping the final outcome of this work.

I am also very grateful to my family, friends, and colleagues for their patience, motivation, and belief in me throughout this process. Their support has given me the strength and confidence to complete this thesis.

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I. Abstract (English)

This thesis examines how blockchain technology can contribute to sustainability in global value chains. Growing concerns about climate change, human rights, and resource scarcity increase the demand for transparency and accountability in international supply networks. Blockchain offers solutions by enabling secure and tamper-proof data, supporting traceability, and facilitating automated processes through smart contracts. Using the collaboration between VeChain and Walmart China as a case study, the research analyses practical applications and evaluates their effects on efficiency, trust, and sustainability. The findings show that blockchain can improve traceability, reduce transaction costs, and enhance social equity, while also revealing challenges such as technical complexity, regulatory uncertainty, and limited scalability. The study contributes to academic debate and provides practical insights for companies and policymakers seeking more resilient and responsible value chains.

II. Abstract (Deutsch)

Diese Masterarbeit untersucht, wie Blockchain-Technologie zur Nachhaltigkeit in globalen Wertschöpfungsketten beitragen kann. Steigende Anforderungen im Hinblick auf Klimaschutz, Menschenrechte und Ressourcenschonung erhöhen den Druck auf internationale Liefernetzwerke, mehr Transparenz und Verantwortung sicherzustellen. Blockchain bietet hierfür Ansätze, indem es sichere und unveränderbare Daten ermöglicht, Rückverfolgbarkeit verbessert und Prozesse durch Smart Contracts automatisiert. Anhand einer Fallstudie zur Zusammenarbeit von VeChain und Walmart China werden praktische Anwendungen analysiert und ihre Auswirkungen auf Effizienz, Vertrauen und Nachhaltigkeit bewertet. Die Ergebnisse zeigen, dass Blockchain Rückverfolgbarkeit verbessern, Transaktionskosten senken und soziale Gerechtigkeit fördern kann, gleichzeitig jedoch Herausforderungen wie technische Komplexität, regulatorische Unsicherheit und eingeschränkte Skalierbarkeit bestehen. Die Arbeit leistet einen Beitrag zur wissenschaftlichen Diskussion und bietet praxisrelevante Erkenntnisse für Unternehmen und politische Entscheidungsträger, die widerstandsfähige und verantwortungsvolle Wertschöpfungsketten anstreben.

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VI. Table of Abbreviations

AI	Artificial Intelligence
BaaS	Blockchain-as-a-Service
CCFA	China Chain-Store & Franchise Association
CE	Circular Economy
CPS	Cyber-physical Systems
CSR	Corporate Social Responsibility
DIG	Direct Imported Goods
ERP	Enterprise Resource Planning
ESG	Environmental, Social and Governance
EVM	Ethereum Virtual Machine
FDI	Foreign Direct Investment
FL	Federated Learning
FTS	Follow-the-Satoshi
GHG	Greenhouse Gas
GVC	Global Value Chain
I4.0	Industry 4.0
ILO	International Labour Organization
IM	Intelligent Manufacturing
IoT	Internet of Things
KYC	know-your-customer
LCA	Life Cycle Assessment
LCT	Life Cycle Thinking
MCT	Multi-Clause Transaction
ML	Machine Learning
MNC	Multinational corporations
P2P	Peer-to-peer
PaaS	Platform as a Service
PoA	Proof of Authority
PoS	Proof of Stake
PoW	Proof of Work
RCEP	Regional Comprehensive Economic Partnership
RFID	Radio Frequency Identification
RTA	Regional Trade Agreement
SaaS	Software as a Service
SDG	Sustainable Development Goal
SM	Smart Manufacturing
TQM	Total Quality Management
QMS	Quality Management Systems
VAT	Value-added Tax
VET	VeChain Token
VTHO	VeChainThor Energy Token

1. Introduction

The convergence of blockchain technology and smart contracts is reshaping industries in ways that were once unimaginable. Within the rise of Industry 4.0, these technologies have influenced the financial sector by creating a new crypto-economy (Khan et al., 2021b), revolutionized healthcare by enhancing data security, interoperability, and patient-centric care (McGhin et al., 2019), and significantly changed the supply chain system by offering end-to-end traceability (Biswas & Gupta, 2019). However, when we think of a better world, we often don't immediately consider these digital technologies, as they are not yet fully understood. Despite their rapid growth and adoption, blockchain and smart contracts are still seen by many as complex and abstract concepts, mainly due to their special design and applications (Zou et al., 2019). Their use involves specific cryptographic principles, distributed systems, and consensus algorithms, such as, e.g., Proof of Work (PoW) or Proof of Stake (PoS), which require a specialized knowledge base and therefore make them less accessible for non-experts.

Nevertheless, blockchain has attracted a lot of attention from governments, organizations, companies, and research institutions. It supports the creation of smart contracts, which allows industries to collaborate with each other by not only solving the problem of trust but also enabling more automated resource allocation on a global scale (Lu, 2019). As industries begin to recognize these applications, their potential to encourage innovation, transparency, and sustainability is becoming more visible.

At the same time, the importance of sustainability in global value chains (GVCs) has never been greater. Rising concerns about climate change, human rights violations, and resource scarcity, particularly in emerging markets, have placed significant pressure on multinational enterprises to adopt more transparent and responsible practices (Marano et al., 2024). Consequently, the demand for solutions that enable traceability, accountability, and efficiency has therefore intensified, creating a fertile environment for blockchain adoption. In this sense, blockchain is not only a technological breakthrough but also a response to global calls for more ethical and sustainable business practices. It offers a bridge between digital innovation and sustainability imperatives, and promises to transform the way firms approach production, distribution, and consumption.

1.1. Background and Context

In 2008, a developer under the pseudonym Satoshi Nakamoto introduced Bitcoin, the first proposed cryptocurrency, which also introduced blockchain as a distributed infrastructural technology (Khan et al., 2021b; Wang et al., 2021b; Zheng et al., 2018). Blockchain could be viewed as a decentralized public ledger where all recorded transactions are stored in a series of interconnected blocks through a cryptographic hash (Zheng et al., 2018). Each block contains a list of transactions, and once added to the chain, the data within it becomes immutable and tamper-proof. This is revolutionary, since unlike traditional centralized systems that rely on intermediaries to validate and store transactions (e.g., banks), blockchain enables exchanges directly between parties through peer-to-peer (P2P) networks, in which computers, or "nodes," communicate directly with one another, eliminating the need for a central server or intermediary (Dzobo et al., 2021). Embedded in blockchains, smart contracts, therefore, allow the contractual terms of an agreement to be enforced automatically, where the contract clauses are written as computer code and are being automatically executed when predefined conditions are met. All transactions are securely stored, replicated, and updated across the distributed blockchains. (Zheng et al., 2018).

Given these properties, digital technologies such as blockchain are increasingly viewed as tools that could be transformative in the fields of FinTech, Internet of Things (IoT), and supply chains (Wang et al., 2021b), and have a huge potential way beyond their initial applications in cryptocurrency, to help traditional organizations evolve and adapt to modern financial and business needs (Zheng et al., 2018). Nowadays, these needs include the sustainable development of firms, which is defined by Demartini et al. (2019) as the production of goods and services, while also prioritizing economic and resource efficiency, environmental accountability and social equity. According to the authors, projections indicate that by 2050, the manufacturing sector will need to produce four times more value than in 2017 while simultaneously striving for zero waste, zero climate emissions, and using only half the current resources.

While traditional sustainability efforts in business have largely relied on regulatory compliance, corporate social responsibility (CSR) initiatives, non-financial reporting, and voluntary environmental commitments to contribute to reducing negative externalities (Lyytimäki et al., 2019; Ortiz-Martínez et al., 2023), these approaches often face some challenges. Current supply chains predominantly depend on centralized and often fragmented databases, which are vulnerable to manipulation, fraud, and inefficiencies (Saberi et al., 2019). Moreover, supply chain sustainability has long been hindered by a lack of end-to-end traceability, making it difficult to verify ethical sourcing, carbon footprints, or fair labour practices (Garcia-Torres et al., 2019). In financial sectors, sustainable investment initiatives such as Environmental, Social, and Governance (ESG) criteria often struggle with inconsistent metrics and limited real-time data, preventing investors from making fully informed decisions (Fatemi et al., 2018). Blockchain technology and smart contracts offer innovative solutions for different industries seeking to enhance traceability and real-time data availability, thereby increasing operational efficiency, and consumer trust, while simultaneously supporting the achievement of long-term sustainability goals.

1.2. Research Gap and Motivation

As businesses have become more interconnected across borders, the environmental, social, and economic implications of their operations have grown increasingly significant. This interdependence has led multinational enterprises (MNCs) to pay closer attention to various global risks, including environmental, economic, societal, geo-political, and technological challenges. Given that MNCs often depend on complex global value chains to optimize production and distribution, the development of GVC capability has become essential for enterprises to improve their resilience (Chatterjee et al., 2024). However, the growing complexity of these networks presents significant challenges in ensuring sustainable development practices (Koberg & Longoni, 2019).

While existing research has largely focused on the technological aspects of blockchain and its role in improving supply chain transparency and operational efficiency (Centobelli et al., 2022; Sunny et al., 2020; Venkatesh et al., 2020), there is a notable gap in exploring its role in addressing complex sustainability challenges, such as environmental degradation, social inequities and inefficiencies in resource allocation, so that more conceptual and empirical investigations are required in this field.

By drawing on existing literature and conducting a case study analysis, this thesis aims to help advance knowledge by exploring how digital innovations, such as blockchain technology, can address sustainability challenges by improving traceability, ensuring environmental compliance, promoting social equity, and simplifying certification processes. Concretely, this paper seeks to answer the following research questions (RQs):

RQ1. How can blockchain technology improve the efficiency and sustainability of supply chains in multinational enterprises (MNCs)?

RQ2. How can blockchain-enabled traceability improve labour conditions and promote social equity in global value chains?

RQ3. How can smart contracts improve resource allocation and reduce certification costs in global value chains?

Therefore, drawing on a case study analysis of the VeChain–Walmart China collaboration, this thesis investigates how blockchain technology can enhance sustainability in global value chains by improving traceability, promoting social equity, and increasing environmental and economic efficiency. Additionally, the study analyses some of the technological, financial, and regulatory barriers to implementing these tools and their implications for scalability and long-term sustainability.

1.3. Objectives of the study

The objectives of this study are the following: to analyse the role of blockchain technology in promoting transparency, traceability, and real-time data availability; to assess the impact of digital technologies on resource allocation, supply chain and logistics optimization, as well as labour management efficiency, and therefore, to try capturing the effect on the environmental, social, and economic factors of corporations, implementing digital technologies.

Moreover, the thesis aims to identify both the benefits and challenges associated with implementing blockchain solutions in GVCs. Through a comprehensive examination of these themes, this research provides valuable insights that will inform both academic discourse and practical policy-making encouraging sustainable development in global commerce.

2. Literature Review

2.1. Overview of Global Value Chains

The concept of the global value chain is central to understanding how supply chains function in today's interconnected world. Antràs and Chor (2022) define global value chains as the series of stages required to bring a product or service from its conception to its end use and beyond, with each stage adding value, and with at least two stages being produced in different countries. Antràs and Chor (2013) compare the process to Henry Ford's original T production assembly line, characterized by a locally optimized, vertically integrated structure with centralized production stages, but also globally coordinated as part of Ford's larger system encompassing materials extraction, transportation, production, assembly, distribution, and sales (Wilson, 2014). Unlike this model, which achieved unprecedented economies of scale through centralization but concentrated both operational control and risk within a single firm and location, today's GVCs are fragmented across multiple countries and firms, since recent revolutionary advances in information and communication technology, along with a gradual decrease in both natural and man-made trade barriers, now allow that (Antràs & Chor, 2013). Moreover, these advancements have led firms to keep only certain stages of production within their own operations and domestic economies (Alfaro et al., 2019), while outsourcing others, thus optimizing efficiency by capitalizing on the comparative advantages offered by different regions.

However, this notion of geographical separation of production stages presents its own set of challenges, particularly in terms of coordination and management. Alfaro et al. (2019) discuss the concept of "separability of ownership" and note that firms rely on arm's-length market transactions, outsourcing production to independent suppliers when ownership separation is feasible. On the other hand, when ownership cannot be easily separated due to factors such as intellectual property concerns, product complexity, or investment-specificity, multinational corporations and foreign direct investment (FDI) become dominant, as firms seek greater control over production processes. This distinction has important implications for sustainability and traceability. In an outsourcing model, where production is dispersed among independent suppliers, firms often face difficulties in ensuring compliance with environmental and social standards. Sustainability oversight becomes fragmented, and traceability is hindered by limited visibility into upstream production stages. As a result, companies may struggle to verify sourcing practices, monitor carbon emissions, or ensure responsible labour conditions across a complex, multi-tiered supply chain.

Blockchain technology offers a promising solution to addressing these sustainability challenges by allowing enhanced monitoring of social and environmental conditions throughout the supply chains (Centobelli et al., 2022). This thesis examines the potential of digital innovation, with a specific focus on blockchain technology, to reshape the management and efficiency of GVCs while promoting sustainability.

2.2. Factors Behind the Rise of GVCs

The “Age of Global Value Chains” began in the early 1980s and has fundamentally transformed international trading flows. Global firms have fragmented their value chains through offshoring and outsourcing, relocating activities to regions where they can optimize production by accessing either specialized capabilities or cost-efficient resources (Ambos et al., 2021). A wide range of technological, institutional, and political advancements has driven this extensive globalization of production processes across nations, leading to a more interconnected and interdependent global economy (Antràs, 2020; World Bank, 2020).

2.2.1. Technological Factors

The rise of Industry 4.0 has accelerated the transformation of manufacturing by introducing a paradigm of automation and data exchange (Xu et al., 2018). Originally a German-led initiative, the concept, sometimes referred to as the “4th industrial revolution”, envisions modular and efficient manufacturing systems in which products and machines can interact intelligently to optimize their own production processes (Lasi et al., 2014). Its core technologies include artificial intelligence (AI), the Internet of Things, cloud computing, and cyber-physical systems (CPS), which optimize operational performance and enable greater customization of production (Dachs et al., 2019; Xu et al., 2018).

At the corporate level, these technologically driven changes in manufacturing systems have played a major role in transforming production processes. Smart Manufacturing (SM), which applies smart technologies for rapid and stable manufacturing of new products, dynamic response to personalized product demands, and real-time optimization of production and supply chain networks, as well as Intelligent Manufacturing (IM), which is defined as the utilization of AI techniques to minimize human involvement into the manufacturing process (Wang et al., 2021a), have created highly adaptive, efficient, and data-driven production systems.

In the context of global value chains, firms increasingly integrate AI and IoT to link customer insights with production. AI-driven analytics, for example, capture consumer preferences and feedback, which are then shared across locations via IoT-enabled systems and cloud platforms. This continuous flow of information enhances operational efficiency, enables customized production, and mitigates supply chain risks.

A concrete example of this integration can be seen in the automotive sector. IoT sensors and Intelligent IoT systems monitor vehicles and components in real time, supporting self-driving features, predictive maintenance, and remote diagnostics. AI, machine learning (ML), and federated learning (FL) allow these systems to process large amounts of data and improve supply chain coordination. Such applications not only optimize production and logistics but also promote more sustainable practices across the global value chain (Ghosh et al., 2022).

Empirical studies further support these benefits: AI has been shown to reduce costs, improve total factor productivity, and increase labour efficiency (Gao, 2022), while IoT connects physical products with digital intelligence, enabling proactive supply chain management and personalized customer experiences (Agrawal et al., 2024).

At the national level, developed countries strategically deploy AI and IoT to strengthen competitiveness and scientific capabilities. These technologies reshape production efficiency, employment structures, and integration into GVCs. Beyond competitiveness, Industry 4.0 also supports sustainability. Research highlights that smart technologies contribute to sustainable manufacturing and broader environmental improvements by enabling resource efficiency and technology-driven progress (Parmentola et al., 2022).

2.2.2. Institutions and Policies

In addition to technological advancements, institutional factors have played a significant role in the proliferation of GVCs. The regulatory environment, trade agreements, and policy frameworks implemented by national governments and international organizations have significantly influenced the geographic distribution of production processes (Kim & Aguilera, 2016). At the same time globalization has been changing the political economy of trade policymaking and other related institutional structures (Anderer et al., 2020).

Liberalization of Trade Policies

According to Anderer et al. (2020), trade policy preferences in a country are shaped by the interests of two main groups: exporters and import competitors. Trade liberalization is generally supported by exporters, as they stand to gain from the increased access to foreign markets. With reduced trade barriers exporters can sell their goods more easily and at competitive prices in international markets, since it is easier for companies to participate in GVCs, sourcing inputs from various countries and selling finished products globally. Import competitors, on the other hand, are likely to lose from liberalization because of foreign competition in domestic markets that can offer lower-cost or higher-quality products. This dichotomy has been a challenge for governments in deciding countries' trade policies.

Gereffi et al. (2021) present a counter-argument to the expectation that trade restrictions lead to the shrinking or disruption of GVCs. They state that the unintended consequences of trade policies, whether restrictions or trade agreements, are amplified by the prevalence and organizational complexity of GVCs. Firms often adapt to trade restrictions by altering their supply chains and production locations, which can lead to a reconfiguration of GVCs. These adaptations allow firms to maintain participation in global value chains and mitigate the immediate negative effects of trade restrictions. However, such reconfigurations can also introduce new vulnerabilities, such as increased operational complexity, dependence on alternative suppliers, and exposure to risks in new production locations. The authors discuss East Asian economies that have successfully applied strategies such as switching production locations and upgrading value chain activities to navigate trade restrictions effectively. Therefore, policymakers should consider the sectoral and temporal variations in how trade restrictions could play out.

Institutional Quality

The institutional dimension encompasses the broader regulatory environment, both formal rules and informal norms, that influence how value chains function and can ultimately reshape their geographic distribution and structural configuration (Bair, 2005; Palpacuer et al., 2005, as cited in Stringer & Michailova, 2018). The quality of national institutions plays a significant moderating role in the nexus between logistics performance and GVC participation. Nasser and Ouerghi (2024) highlight that high institutional governance has positive impact on the participation of corporations in GVCs. Well-functioning institutions enhance logistics performance, which in turn strengthens a country's ability to integrate into global trade networks. Conversely, weak institutions, such as inadequate regulatory frameworks or poorly developed infrastructure, can undermine the benefits of trade liberalization by limiting the effectiveness of logistics systems. Beyond trade, institutional quality has also been shown to play a critical role in sustainable development outcomes. Environmental regulations may exist on paper but are frequently under-enforced due to limited institutional capacity or corruption, resulting in pollution, improper waste disposal, and unsustainable resource extraction (Stringer & Michailova, 2018). Moreover, in some low-income countries, weak enforcement of labour laws has led to exploitative working conditions, including excessive working hours, unsafe factory environments, and child labour – for example, the garment sector in Bangladesh has repeatedly experienced factory collapses and safety incidents, highlighting the consequences of inadequate regulatory oversight.

By contrast, countries with stronger institutional frameworks are better positioned to ensure that GVCs adhere to both labour and environmental standards. Azam et al. (2021), examine empirical evidence from 66 developing countries between 1984 and 2019 that demonstrates that strong institutional frameworks contribute positively to sustainable development. The authors base their analysis of the impact of institutional quality on the sustainable development of firms on total factor productivity improvements through effective environmental regulation and abatement policies. The impact of institutional quality is found to be greater in lower middle-income countries compared to low-income countries, highlighting the differentiated capacity of institutional environments to support long-term development goals. This underscores the necessity of legislative enforcement and tailored institutional designs to ensure that environmental resource management policies are both efficient and productive.

<u>The Role of ISO Standards</u>

International standards set by the ISO are a key factor behind the rise of GVCs. They not only establish common benchmarks for quality, safety, and management systems, such as ISO 9001 and ISO 14001, but also allow firms from different countries to benefit by their collaboration (Tarí et al., 2012). Companies achieve internal positive effects on operations and personnel and also external benefits regarding a look of reliability, particularly for firms in developing economies seeking to integrate into global production networks.

However, research has shown that while ISO 9001-based Quality Management Systems (QMS) have been widely adopted as part of Total Quality Management (TQM) strategies to achieve continuous quality improvement, their outcomes have sometimes been limited due to the lack of immutability and traceability in current practices. Muruganandham et al. (2023), highlight that this limitation can be addressed through the integration of blockchain technology with ISO 9001:2015 QMS, using smart contracts and hyperledger to enhance traceability and immutability, and potentially IoT and AI to further strengthen continuous improvement processes. This integrated framework could advance the effectiveness of ISO-driven quality systems and also reinforce the credibility and sustainability of firms participating in global value chains.

2.2.3. Political and Economic Influences

The globalization of production has been significantly driven by the opening of emerging markets, and the liberalization of foreign direct investment regimes. Opening borders to international trade and investment allows greater participation in global production networks and grants access to advanced technologies, capital, and managerial expertise (Banday et al., 2021). These developments have integrated emerging economies and helped developing countries to participate more actively in GVCs.

Moreover, the adoption of regional trade agreements (RTAs) has made cross-border production and investment more efficient, and has promoted economic development (Tian et al., 2022). Tariff elimination through duty-free trade reduces costs and helps increase economic activity with cross-border production and exchange. In contrast, instances of protectionism, such as the recent tariffs imposed during the U.S.-China trade conflict under the Trump administration, highlight the fragility of GVCs. They increase production costs, disrupt supply chains, and encourage firms to reassess the geographic configuration of their operations. Therefore, stable and predictable trade policies are a need to maintain the efficiency and resilience of supply chains.

2.3. Sustainability Challenges in GVCs

Sustainability in global value chains is a complex and multifaceted concept that demands a holistic approach which integrates economic, environmental, and social dimensions to effectively address its challenges (Berthet & Fusacchia, 2024). Although it has been incorporated into multiple theoretical frameworks of chains and networks (Antràs & Chor, 2022; Chor, 2019; Johnson, 2018; Kano et al., 2020), there seems to be an absence of a unified academic consensus on one theoretical framework.

Companies nowadays have to report a number of ESG metrics, as required by investors, regulators, and stakeholders (Edmans, 2023). Most of these metrics, however, lack commensurability and theorization, and require a critical analysis (Keeley et al., 2022). Indicators and not always comparable and different firms use different standards. While some focus more on environmental issues, others concentrate on social and governance aspects. This makes it hard to judge the real performance. In GVCs the problem gets even bigger - data often comes from many suppliers across borders, and verification could be difficult. The impact of ESG reporting gets weaker and trust becomes a challenge.

A possible way to overcome these issues of inconsistency, limited comparability, and low trust is the adoption of blockchain-based reporting systems. By functioning as a decentralized ledger, blockchain secures information through its immutable chain structure, ensuring both transparency and protection against tampering (Gong et al., 2024). This allows companies and suppliers across different tiers of global value chains can record standardized, verifiable information in real time.

2.3.1. Environmental Impact

Among the three pillars of sustainability, the environmental dimension has received a lot of attention in academic research due to the measurable and often global impact of emissions and resource use. Its quality has been affected majorly by GVCs and several studies have reported on it. Yuan et al. (2024) delve into backward and forward participation in GVCs and how they may have different implications and conditioning effect on carbon emissions and mineral resources. Forward participation, which according to Kim (2024) refers to a country's involvement in exporting goods and services that are part of a larger production process, can reduce carbon emissions if countries decide to adopt cleaner technologies and practices. Qian et al.'s (2022) study indicates that increased forward participation in RCEP countries reduces CO_2 emissions primarily through improvements in production technology, with each 1% increase in forward participation leading to a significant decrease in emissions of approximately 14.35%. Backward participation on the other hand, characterized by foreign content in domestic exports, could lead to higher emissions if those foreign suppliers follow lower environmental standards than domestic producers. This is particularly concerning in industries reliant on energy-intensive raw material extraction and processing.

Ali and Wang (2024) further highlight the complex impact of participation in GVCs on environmental quality. The authors argue that both forward and backward participation in GVCs tends to improve environmental quality, aligning with the pollution halo hypothesis, which suggests that countries engaged in GVCs may adopt cleaner technologies and practices due to international standards and pressures. The effects, however, vary across income levels, with developed and emerging economies benefiting from GVCs, while developing and underdeveloped economies experience negative environmental impacts. This disparity is further emphasized by Kshetri (2021) and Doryń and Wawrzyniak (2024), who highlight that sustainability violations are more prevalent in lower tiers of supply chains within developing countries, where weak regulations and enforcement mechanisms related to environmental sustainability exacerbate sustainability challenges. These environmental issues highlight that especially in the lower tiers of supply chains of developing economies, the fragmented nature of global production makes it difficult to trace environmental practices and verify sustainability claims across borders.

2.3.2. Social Equity and Labour Rights

The intersection of social equity and labour rights within global value chains is increasingly recognized as essential for sustainable development, particularly as globalization continues to reshape production and labour dynamics. As MNCs expand their operations across borders, they gain significant influence over shaping labour standards and working conditions. Within complex GVCs where labour practices are diffused across multiple tiers of suppliers, modern slavery often operates covertly (Stringer & Michailova, 2018), making it difficult to detect and address.

The term “modern slavery” is very complex and lacks a single, universally accepted definition, however, Han et al. (2024) describe it as encompassing practices such as forced labour, human trafficking, and illegal employment, all of which severely limit workers' freedom and subject them to significant suffering. Moreover, Mende (2019) provides a framework for understanding modern slavery by focusing on three critical denominators: the control of a person over another, an involuntary aspect in their relation, and the element of exploitation. Control highlights the significant power imbalance in these relationships, effectively stripping the victim of their autonomy and freedom. Involuntariness suggests that many individuals find themselves in circumstances where they lack the freedom to choose or change their situation due to different factors such as poverty, lack of education or limited job opportunities. The element of exploitation refers to the unfair treatment of individuals for the benefit of others that often involves extraction of labour without just, if any, compensation.

According to the ILO’s (2022) latest estimates, 27.6 million people were in situations of forced labour on any given day in 2021. The Asia-Pacific region accounted for the highest number, with 15.1 million victims. Of the total, 6.3 million people (37%) were exploited in industry, while 5.5 million (32%) were in the services sector, including wholesale and food services. Forced labour in the service sector alone generates an estimated US $20.9 billion in illegal profits annually.

There is an ongoing discussion about whether modern slavery is a global issue affecting both developing and developed countries or if it is predominantly confined to the former. According to Christ and V Helliar (2021), a major concern is the inadequate enforcement of labour laws, which often leaves migrant workers from developing countries vulnerable to exploitation, since they are looking for a better life for themselves and their families, and could easily fall victim to human trafficking and deceptive recruitment.

Furthermore, Scherrer (2017) highlights the trade-off developing countries have to face – adhering to higher labour standards can incur their short-term costs which puts them at a competitive disadvantage compared to companies with more capital. As a result, economic pressures limit their ability to independently implement stronger labour protections, as they fear losing market share to nations that do not uphold such standards. On the other hand, Stringer and Michailova (2018) focus on the perspective of MNCs, emphasizing their drive for cost minimization. Producers and labour-market intermediaries try to capitalize on market opportunities by reducing labour costs, often exploiting a cheap and largely unprotected workforce (ILO, p. 63, 2005) to maximize profit margins. Additionally, MNCs' suppliers are exposed to significant pressure and strict conditions on price and delivery of products. This pushes them to outsource labour-intensive, lower-value activities to sub-tier suppliers, who may then further delegate tasks down the supply chain (Stringer & Michailova, 2018). This creates complex, multi-layered subcontracting networks that make oversight and accountability incredibly difficult.

Many researchers argue that modern slavery is a prevalent problem also in developed countries (Christ & V Helliar, 2021; Stringer & Michailova, 2018). However, it manifests differently due to different socio-economic and legal factors (Mehmood et al., 2023). Developed countries usually have more comprehensive modern slavery laws and regulations in place. Moreover, the economic conditions in developing countries predispose an environment in which people are more vulnerable to exploitation, while stability helps avoid such situations. Differences in cultural and social norms also contribute to significant differences, since in many developing countries practices such as child labour can be traditional and normalised.

It is perhaps unsurprising that slavery persists in both developed and developing countries, given the frequent lack of reliable data on modern slavery, making it difficult to understand the full scope of the issue. It is difficult for MNCs to track exploitation withing their supply chains (LeBaron, 2014 as cited by Christ & V Helliar, 2021), and this raises the question of the reliability of social audits and reporting.

2.3.3. Economic and Resource Efficiency

Sustainable manufacturing, or also efficient manufacturing, focuses on the production phase of the whole product life cycle while also considering the economic and environmental impacts across all other stages (Blume, 2020). It could be achieved through an efficient strategy by either minimizing resource inputs, maximizing product outputs or combining both. It is imperative for manufacturing competitiveness (Margherita and Braccini, 2020, as cited by Ching et al., 2022). Corporations are advised to use resources efficiently in both economic and environmental terms, as they can not only be cost-effective but also reduce the negative environmental impact of firms' activities (Delmas & Pekovic, 2015).

<u>Cost Optimization in GVCs</u>

One of the primary factors for firms for maintaining competitive advantage and ensuring long-term sustainability of their business is the effectiveness of cost management in GVCs. Implementing sustainability initiatives often involves higher upfront costs (Ching et al., 2022). Operating within complex, cross-border supply chains, firms must carefully balance cost efficiency with their strategic investments. A key consideration in this process is whether sustainability efforts should follow a goal-oriented or contribution-oriented approach (McIntyre et al., 2016). The former suggests that the corporation sets clear objectives and then invests whatever is necessary to reach them, providing a clear understanding of the expected outcomes. However, the risk is that the actual costs could exceed expectations, potentially making the company less competitive. In contrast, a contribution-oriented approach involves the corporation setting a budget for sustainability efforts and then determining what can be accomplished within that financial limit, which offers greater protection against cost overruns and maintains competitiveness. This approach may however limit the scope of sustainability initiatives, leading to lower impact and less clear outcomes. This trade-off presents a significant challenge: how can businesses effectively integrate sustainability commitments without compromising financial stability and market competitiveness?

Life Cycle Assessments (LCA) and Sustainability Optimization

One way to navigate this challenge is through the application of Life Cycle Assessments (LCA). Life Cycle Thinking (LCT) is a holistic approach to assessing the environmental burdens of products, sectors, or projects from raw material extraction to end-of-life (Sala et al., 2021). It aims to prevent burden shifting across environmental impact categories, world regions, or life cycle stages. Together with Life Cycle Assessment, it provides a structured methodology to quantify environmental impacts at each stage of product's life cycle, as LCA offers quantitative information on the environmental performance of goods and services. However, this information is often too complex for decision-makers who need clear, actionable insights rather than just raw data. There is lack of interpretation tools that could convert the results of LCA into simple recommendations, thus making the results rarely conclusive (Angelo et al., 2017). Moreover, while LCA could provide quantitative environmental data (e.g., carbon footprint, water use), it doesn't offer a single metric that integrates environmental, economic, and social impacts in a universally accepted way, making decision-making more difficult when taking other sustainability factors in account (Torkayesh et al., 2022).

Circular Economy

The concept of circular economy (CE) has emerged as a way to obtain more value from resources while reducing material throughput. Unlike the traditional linear model of "take, make, dispose", it involves closed-loop and cooperative approaches, reuse, adaptation, resource stewardship, stock management, sharing, and other business models (Ness & Xing, 2017). It aims to minimize the extraction of natural resources and the generation of waste by promoting a cyclical use of materials, aligned with the principles of cleaner production and the three Rs: reduce, reuse, and recycle (Murray et al., 2017, as cited by Upadhyay et al., 2021). The concept has attracted attention from both researchers and practitioners, since it offers a practical approach for businesses to take real action towards sustainable development. Moreover, it is seen as a response to growing resource limitations and an opportunity for a shift toward a more sustainable economic model (Mies & Gold, 2021).

Nevertheless, achieving a circular economy is considered a significant challenge. Applying circular solutions requires technical and non-technical capabilities and may not always be cost-competitive with linear alternatives (Kirchherr et al., 2017; Meier et al., 2023). Many firms still prioritize short-term profit over long-term sustainability. Practical implementation is further hindered by the lack of standardised metrics, limited infrastructure, as well as consumer's willingness to cooperate, e.g., by culture habits, or perceived inconvenience.

Furthermore, interoperability and effective information sharing among ecosystem actors are essential requirements for advancing the circular economy (Barata et al., 2022). Without common standards and transparent data exchange, the tracking of recycled materials, verification of reuse practices, and coordination across different supply chain tiers remain fragmented and inefficient. Through end-to-end traceability blockchain could help overcome this gap by verifying the origin and quality of recycled inputs, and ensuring that reuse and recovery claims are accurate and tamper-proof.

2.4. Blockchain Technology in GVCs

The integration of blockchain technology offers significant potential to address the inefficiencies and sustainability challenges in global value chains. Sunny et al. (2020) argue that centralized traceability solutions are not preferable for supply chains, since they are exposed to many problems such as data manipulations and single point of failure. The authors highlight that blockchain could provide a decentralized and immutable ledger for recording supply chain transactions which would allow stakeholders to track products from their origin to the final consumer faster and more easily. This could ensure greater accountability and reduce risks associated with unethical practices.

2.4.1. Fundamental Concepts

Before this thesis dives into some of the potential applications of blockchain technology for solving urgent sustainability issues, it is important to first clarify the fundamental concepts in connection with these innovations.

Blockchain

In recent years, the topic of blockchain has gained increasing attention in academic and industry research with the various advantages and challenges associated with its implementation. Over the last few years, studies have also begun to explore the intersection of AI and machine learning with blockchain (Kayikci & Khoshgoftaar, 2024; Ressi et al., 2024), demonstrating that these digital innovations are not only advancing with time but also have strong potential for synergy.

Blockchain is a decentralised and immutable digital ledger or database without a central trusted intermediary that records transactions in a chronological chain of blocks (Bodó et al., 2018; Kayikci & Khoshgoftaar, 2024). Any type of data could be recorded on the ledger, including information about the transactions, thus allowing it to also be used for tracking token balances of different nodes, or “wallets”, so that a token could not be spent more than once (Bodó et al., 2018).

Figure 1 offers a simplified explanation of how the technology works. After a request for a transaction has been made by one of the blockchain participants, transmitted through a P2P network and broadcast to all other participants (nodes) in the system. They receive the request and validate the transaction using a consensus mechanism. Once approved, the transaction is recorded in a block and added to an existing chain, thus completing the transaction. Everyone with access to the ledger can view all transactions and records stored on the blockchain (Bodó et al., 2018).

Traditional structures usually consist of several ledgers maintained by different parties, all connected to a central party ledger, where each node relies on it as the master record (Hughes et al., 2019). These structures have several limitations such as a single point of failure, increased costs, and dependence on the trustworthiness and security of the central authority.

Blockchain’s structure is innovative because it eliminates this need for a centralized trusted party and instead allows each node in the network to transact directly with the other nodes through an agreed-upon consensus mechanism. As a result, blockchain fundamentally reshapes how trust and coordination are established in digital environments.

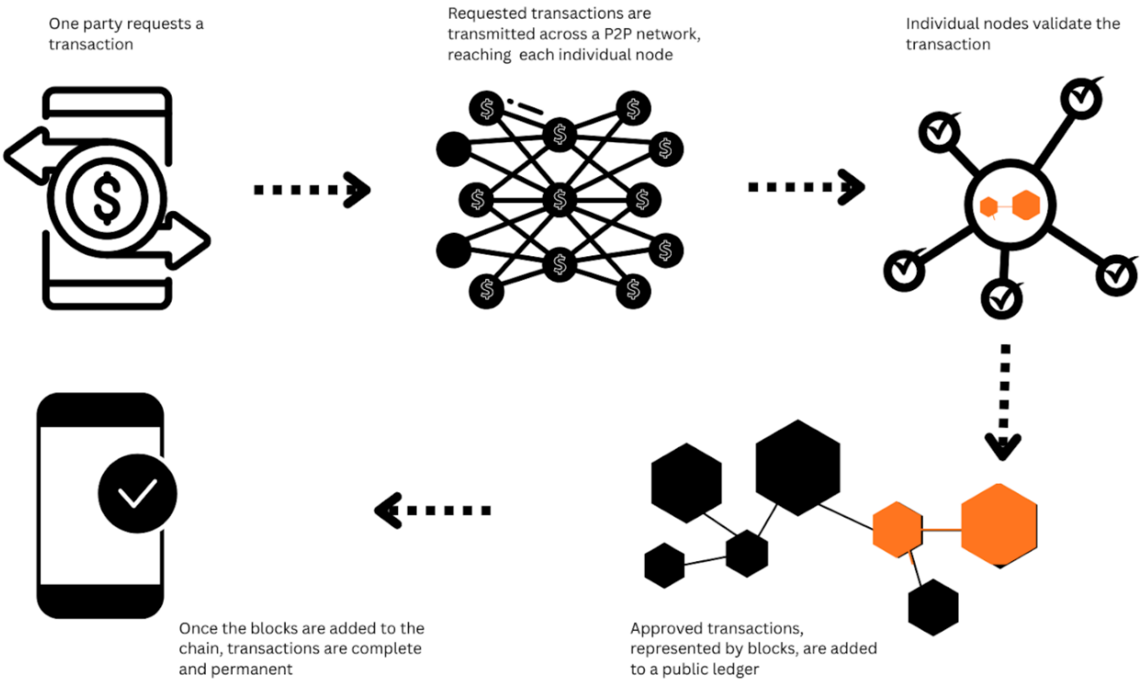

Figure 1: An illustration of how blockchain works

<u>Types of Blockchain and Consensus Algorithms</u>

There are several types of consensus algorithms with different strengths and limitations. Depending on the type of blockchain system – public (permissionless) or private (permissioned), a different consensus algorithm is used to agree on which transactions get added to the ledger. Public blockchains are decentralized, permissionless networks in which every participant has access to the complete ledger and the ability to propose and validate transactions (Bamakan et al., 2020), e.g., Bitcoin and Ethereum. These networks usually utilise the Proof of Work (PoW), Proof of Stake (PoS), and other consensus algorithms.

Proof of Work is the consensus algorithm earliest adopted in blockchain (Hu et al., 2021, as cited by Wendl et al., 2023). In this algorithm, the validation of transactions is carried out through a process known as mining, where nodes use significant computational power to solve complex mathematical problems by trial and error (Wendl et al., 2023). This process secures the network by making it prohibitively expensive to manipulate transaction history, and determines which miner gets to add the next block to the blockchain. Only the first miner to successfully solve the complex computational challenge is allowed to generate the hash identifier and append the new block to the blockchain.

Proof of Stake was introduced in 2012, to help with the issue of high resource consumption of PoW. Within this algorithm, the nodes are called validators, who are "randomly" selected to create new blocks based on the amount of cryptocurrency they have staked (Saleh, 2021). In the basic version of Proof of Stake, called the Follow-the-Satoshi (FTS) algorithm, the system randomly picks one coin from all the coins in the network. The person who owns that specific coin is then chosen to create the next block and receives a reward for doing so. Table 1 below compares the PoW and PoS consensus algorithms and explains some of their differences.

Table 1: Comparison of Proof of Work and Proof of Stake

Criteria	Proof of Work	Proof of Stake
Block Creation	Miners solve complex puzzles to validate transactions	Validators are selected based on stake and sometimes randomness
Energy Use	High computational effort and energy use	Low energy use; no mining hardware needed
Security Threat	51% attack requires majority hash power	51% attack requires majority of all stake
Reward Mechanism	First to solve the puzzle gets block reward	Validators earn transaction fees or new coins depending on protocol

Moreover, it covers the factor of security threat, particularly the so-called 51% attack, in which a malicious actor could compromise the network either by controlling over 51% of the total computational power in PoW systems or by owning more than 51% of the total cryptocurrency in circulation in PoS systems.

In contrast to public blockchains, private blockchains are permissioned systems where the access to the network is restricted to a select group of nodes. A central authority governs the network, granting specific permissions to participants regarding who can read, write, or validate transactions on the blockchain (Bamakan et al., 2020). Therefore, the consensus mechanism in private blockchains has a single central authority. One such mechanism is the Proof of Authority (PoA), which can also be seen as a form of PoS with less costs (Manolache et al., 2022). It relies on the credibility and trustworthiness of a limited number of validators. This trustworthiness is ensured by a rigorous validation of identity with the process having to be sufficiently complex to deter malicious actors from infiltrating the system.

Smart contracts

Smart contracts are self-executing programs deployed on a blockchain that autonomously carry out and enforce agreements between parties without requiring a trusted third-party (Buterin et al., 2014, as cited by Khan et al., 2021b). They are typically written in programming languages like Solidity (widely used on Ethereum) and are triggered when predefined conditions encoded within them are met. This automation eliminates the need for manual execution or enforcement and reduces transactional friction and costs. Typical feature of smart contracts is that they are copied to every node of the network which is what makes the data tamper-proof. In this way, the possibilities of downtime, fraud, or interference are reduced.

However, limitations such as lack a consensus on how code-based agreements align with traditional legal concepts of contract law present some major concerns (Bodó et al., 2018). Questions remain around issues such as legal enforceability, dispute resolution, and liability in cases where the code executes in unintended or unfair ways.

2.4.2. Potential Applications for Sustainability

Sustainability has become a long-term goal for both consumers and enterprises, recognising that while industrial production contributes significantly to modern quality of life, it is also a major driver of environmental and industrial challenges (Demartini et al., 2019). So how can digital technologies such as blockchain be helpful in the sustainable development of firms? The use of such innovations requires, first – awareness of their potential, and second – a willingness to transform the manufacturing processes and organisational culture of a company. Effective supply chain transparency requires the active participation of all companies and partner agents involved across the entire supply network, ensuring that relevant information is consistently shared and accessible at every stage (Bai & Sarkis, 2020).

Transparency & Traceability

One of the most widely discussed applications of blockchain in the context of sustainability is its ability to improve traceability and transparency across supply chains. In complex GVCs the tracking of products and even services becomes a challenge. The difficulty to track the origin of products, verify compliance with environmental standards, or ensure ethical labour practices leads to inefficiencies, fraud, and negative environmental or social externalities. Blockchain technology supports the development of supply chains with enhanced traceability and transparency, especially when integrated with advanced tracking systems such as RFID and GPS (Centobelli et al., 2022).

There is a subtle but important difference between transparency and traceability. Transparency refers to how easily relevant information can be accessed and understood by all parties involved in a transaction, as well as by external stakeholders or observers. In the context of supply chains, transparency refers to the extent to which information about products, processes, and practices is openly available and accessible to both end consumers and the companies involved throughout the supply chain (Bai & Sarkis, 2020).

Traceability, on the other hand, is the technical capability to track and trace a product’s path through each stage of the supply chain, from the sourcing of raw materials through manufacturing, distribution, and ultimately to the final consumer. Traceability goes beyond regulatory compliance or operational efficiency - it is also essential for maintaining product quality and promoting sustainable practices (Payandeh et al., 2025). Therefore, while transparency relies on the willingness to disclose information, traceability ensures that the data exists and can be followed through the entire lifecycle of a product.

Supply chain traceability has a key role in today’s business operations, and blockchain technology, in combination with other Industry 4.0 technologies like the IoT and Radio

Frequency Identification (RFID), has shown strong potential to improve it by strengthening supply chain security, increasing transparency, improving data protection, and ensuring greater reliability (Kumar & Kumar Singh, 2022; Payandeh et al., 2025). The decentralisation of blockchain reduces single-point failures and allows for the secure processing of transactions (Kumar & Kumar Singh, 2022). Furthermore, the immutability of blockchain records ensures that once data is recorded, it cannot be altered retroactively, thus, reducing the risk of fraud. The real-time tracking of data provided in different ways, e.g., with the help of blockchain labels, assures consumers that the product information they find is traceable, accountable, and secure (Zhang et al., 2024). This combination of traceable data and tamper-proof records improves the ability of corporations to monitor social and environmental conditions (Centobelli et al., 2022), therefore offering information on the compliance with sustainable and ethical sourcing standards, as well as human rights, and therefore, builds trust among different stakeholders.

In recent years, many researchers have increasingly focused their efforts on the applications of blockchain, with particular attention to food supply chains (Iftekhar et al., 2020; Liu et al., 2025; Yu et al., 2024). Usually, authors mention successful blockchain initiatives like Hyperledger, IBM Food Trust, and TE-FOOD that demonstrate how distributed ledger technologies can enhance traceability, transparency, and accountability in the food industry. These initiatives serve as prominent examples of how blockchain is being deployed to track the origin of food products, monitor transportation and storage conditions, and ensure compliance with safety standards in order to control and avoid the occurrence of health and safety problems (Centobelli et al., 2022).

However, it is important to note that significant challenges for both governments and businesses come together with the implementation of effective traceability systems (Payandeh et al., 2025). The thesis addresses several of these challenges in later sections.

Environmental Impact

Due to enhanced transparency and traceability, blockchain enables companies and consumers to verify the origins, production processes, and supply chains of goods, therefore ensuring that supply chain processes are truly sustainable. Beyond this, blockchain also holds great potential in advancing circular economy. It can enhance recycling performance and contribute to waste reduction (Centobelli et al., 2022) by monitoring long and complex supply chains and ensuring good product-quality, as well as cleaner production (Upadhyay et al., 2021). In this way, this disruptive digital technology can also help detect counterfeit products (Duan et al., 2020, as cited by Munir et al., 2022), improve resource efficiency by enabling real-time tracking of material flows, and minimise overconsumption. Moreover, through the use of smart contracts, carbon taxation policies can be automatically implemented and continuously monitored, to ensure compliance and to enhance the effectiveness of emissions reduction strategies (Munir et al., 2022).

Parmentola et al. (2022) highlight that blockchain can actively support circular economy objectives through its contribution to several Sustainable Development Goals (SDGs) (Figure 2). Most notably, by the transparent tracking of products across the supply chains it facilitates SDG 12 - Responsible Consumption and Production (Saberi et al., 2019), allowing consumers to make informed decisions about the products they buy and helping companies monitor and improve the sustainability of their supply chains. Moreover, it supports Sustainable Cities and Communities (SDG 11) by enabling platforms that monitor energy use, waste, and resource flows in urban environments (Ahad et al., 2020). It can also incentivize environmentally responsible behaviours and penalize harmful actions such as water pollution (SDG 14) or biodiversity loss (SDG 15), thereby reinforcing resource conservation and regenerative practices (França et al., 2020).

Parmentola et al.'s (2022) systematic literature review and content analysis of several selected papers further explore the relationship between blockchain and environmental Sustainable Development Goals, mentioning that while blockchain can support them by e.g. improving supply chain transparency or enabling renewable energy trading, most traditional blockchain systems, especially proof-of-work mechanisms like in Bitcoin, consume a large amount of energy, and actually pose challenges for the natural environment. For instance, a single Bitcoin transaction can generate a carbon footprint comparable to driving a gas-powered car for hundreds of miles. Beyond energy consumption, PoW mining also contributes to electronic waste, as outdated mining hardware becomes obsolete. It is important to consider that these environmental impacts are not inherent to blockchain as a technology but are largely associated with the energy-intensive consensus mechanisms currently in use.

Figure 2: The 17 United Nations Sustainable Development Goals (United Nations, 2015)

Alternative approaches, such as PoS or hybrid consensus models, as well as the use of renewable energy sources, can substantially reduce blockchain's ecological footprint while preserving its potential to advance environmental Sustainable Development Goals.

<u>Social Impact</u>

As a significant component of corporate social responsibility, social audits have long been used to monitor labour conditions in global supply chains. However, they are increasingly criticized as superficial, compliance-oriented assessments that offer only a snapshot of reality, often failing to detect hidden abuses, unregulated subcontracting, or systemic issues like forced labour. The pressing issue of social equity nowadays questions the efficacy of traditional social audits and highlights the increasing pressure on governments and large businesses to identify and reduce the incidence of modern slavery in corporate activities (Christ & V Helliar, 2021).

Blockchain technology offers more than an opportunity for product tracking – it could also be seen as an effective tracking tool for the social implications of MNCs, as it makes it more difficult for companies to hide unethical practices. It is a possible solution for social inequity and unfair compensation. Sharif and Ghodoosi (2022) examine the role of blockchain in organisations and how it could create a more ethical work environment. One way is through the use of smart contracts, where the payment process can be automated with the payments going directly to workers or suppliers, and therefore, reducing wage theft, delays, and exploitation by intermediaries. This is especially relevant for certain groups of workers, such as ones from developing countries, given that they usually do not have the resources for legal protection and thus have little recourse if they are underpaid or unpaid.

Recent research further highlights that the effectiveness of blockchain in addressing such labour-related issues depends not only on the technology itself but also on the organisation's capabilities to implement it. Yu et al. (2024) show that employees' digital dexterity, defined as the ability to adapt to and leverage digital tools, drives strategic investment in blockchain, which in turn enhances a firm's internal modern slavery capabilities. These internal capabilities mediate the impact of blockchain investment on modern slavery capabilities with both customers and suppliers, underlining that blockchain's potential to combat labour exploitation is maximized when paired with the right organizational skills and commitment.

Next to this mediation effect, there are some risks involved with the use of blockchain technology for social equity. The so-called "garbage in, garbage out" problem that suggests that companies can enter false wage figures, fake supplier IDs, or misleading sustainability claims remains. Through third-party verification (e.g., independent auditors), the data can be verified before it's recorded, but it weakens one of blockchain's selling points - no need for a central third party. This limitation will be discussed in greater detail later in the thesis.

Economic Impact

Companies nowadays are well aware that next to a sustainable practice, a good reputation is closely linked to improved financial performance. Blockchain motivates participants to pursue long-term solutions to emissions through a reputation-based system (Esmaeilian et al., 2020, as cited by Munir et al., 2022) and offers potential to transform economic activities far beyond the financial sector.

In multijurisdictional contexts, the complexity of tax laws and varying reporting requirements makes compliance costly and error-prone. Blockchain's transparency and automated record-keeping ensure that all transactions are accurately documented and traceable, which can reduce compliance-related costs, such as those associated with value-added tax (VAT) in cross-border trade typical of online marketplaces and platform-based commerce (Cho et al., 2021).

Furthermore, by removing intermediaries, increasing automation through smart contracts, and improved transparency, blockchain can reduce transaction costs. This is achieved by shortening transaction execution time and increasing transaction volume in GVCs (Chen et al., 2022). In a fully decentralized blockchain market, participants can join GVC networks and transact via the consensus mechanism, further lowering costs. However, Chen et al. (2022) note that bargaining costs may increase when transaction information is difficult to verify, as human intervention becomes necessary, making the design of smart contracts more complex and costly.

With today's complex industrial systems and evolved supply chains, increasing operational efficiency has become a critical priority for corporations. Valuable information for decision-making has to be trusted for the efficient production planning, resource allocation, and the overall competitiveness of companies in the market. Blockchain technology, together with Industry 4.0 technologies has created an increasingly integrated ecosystem for production planning and control (Gangwani et al., 2023, as cited by Bai et al., 2024). Its implementation addresses several persistent challenges in cross-border trade. Tian et al. (2024) highlight evidence from field experiments that shows how blockchain can significantly reduce operational, agency, and time-related costs.

Bai et al. (2024) question, however, whether companies are really able to implement blockchain effectively in operational and strategic planning and whether measurable performance improvements can be achieved in real-world supply chains. The growth and influence of blockchain technology continue to increase over time, yet its adoption is hindered by many complexities, including technological integration challenges, governance issues, and the need for coordination among multiple stakeholders. Therefore, while blockchain holds significant potential, its practical impact remains contingent on organizational readiness, effective implementation strategies, and empirical validation in real-world contexts.

3. Research Methodology

3.1. Research Design

This thesis adopts a qualitative single-case study design to explore how blockchain technology, and specifically the VeChain-Walmart China collaboration, contributes to addressing sustainability challenges in global value chains. A qualitative approach is particularly suited for emerging technologies such as blockchain, where the phenomenon is not yet widely understood and empirical data remains limited. According to Gammelgaard (2017), the term ‘qualitative’ suggests an inquiry into the meaning of concepts within their specific contexts – essentially, a narrative that seeks to make sense of real-life challenges and situations. The method is selected for its ability to provide an in-depth exploration of real-world applications of blockchain in sustainability initiatives. Additionally, it enables a detailed investigation of a contemporary phenomenon within its real-life context, making it particularly suitable for studying emerging technologies such as blockchain (Yin, 2018).

The research focuses on the particular case of VeChain – a blockchain platform specializing in supply chain management and logistics, which has been actively implementing blockchain solutions across various industries, including fashion, luxury goods, and food supply chains, and its collaboration with Walmart China. It follows an exploratory approach to identify the key mechanisms throughout this initiative that have contributed to improving sustainability measures in GVCs. While explanatory research seeks to understand the reasons behind a phenomenon, exploratory research fits this thesis better, as there is a limited number of existing studies related to it. The methodological foundation rests on secondary data from academic literature, peer-reviewed journal articles, industry reports, company whitepapers, VeChain and Walmart sustainability disclosures, and ESG and annual reports. It aims to provide a comprehensive perspective on the initiative, while balancing corporate self-reported claims with independent evaluations.

3.2. Case Study Selection

According to Flyvbjerg (2006), there is a list of selection criteria for case studies in social science that could also be also useful for logistics and SCM case research. The author emphasizes that cases should primarily be selected based on their potential to provide rich, detailed insights rather than their ability to be generalized. This case-study follows this logic of purposeful sampling with several factors that justify its selection:

1. **Relevance to Research Questions**: Walmart China faces acute sustainability challenges in food supply chains, including food safety, traceability, and waste reduction. VeChain's blockchain solution directly addresses these issues, aligning with this thesis's research questions on transparency, social equity, and resource allocation.
2. **Empirical Richness:** The initiative is well-documented through company reports, industry publications, and whitepapers, providing a strong base of secondary data for analysis.

3.2.1. VeChain's Projects

Furthermore, to justify the selection of this initiative, the study first examined VeChain's cross-industry applications in sectors such as fashion, pharmaceuticals, and automotive, in order to assess the scalability and transferability of blockchain solutions across different global value chains **(3).** VeChain has been actively involved in several projects that improve transparency and traceability in supply chains, particularly in industries with significant sustainability challenges. Table 2 shows some of VeChain's collaborations since 2018, such as e.g., the one with Shanghai Waigaoqiao Direct Imported Goods (DIG) for authenticating luxury wines imported through Shanghai's Pilot Free Trade Zone (VeChain, 2018). By embedding NFC chips into wine bottles and logging data on the VeChain blockchain, the project not only provided full transparency from vineyard to consumer, but also increased DIG wine sells (PR Newswire, 2019).

Other notable VeChain partnerships include its 2019 collaboration with BMW to develop VerifyCar, a blockchain-based system designed to track vehicle history, mileage records, and repairs (BMW Group, 2019). In the same year, VeChain also partnered with H&M's premium brand COS to enhance transparency within its sustainable fashion line (VeChain Foundation, 2020). Through blockchain-enabled product tracking, customers could scan QR codes on COS garments to access verified information regarding the origin of organic materials, supplier certifications, and production processes. Moreover, the deployment of the platform by Bayer China in 2019 to track pharmaceuticals across the supply chain (Bayer China, 2020) has improved drug safety, reduced counterfeit medications, and ensured regulatory compliance by providing a secure and transparent tracking system (VeChain, 2019).

Table 2: Comparative overview of VeChain's cross-industry partnerships

Criteria	VeChain & H&M	VeChain & DIG	BMW & VeChain	Bayer & VeChain
Industry Focus	Fashion, luxury goods, and supply chains	Luxury goods (wine authentication)	Automotive (vehicle history tracking)	Pharmaceuticals (drug safety, counterfeit prevention)
Sustainability Focus	Transparent sourcing, sustainable production, ethical labour	Product authenticity, counterfeit prevention, consumer trust	Vehicle lifecycle transparency, sustainability of auto parts	Pharmaceutical safety, regulatory compliance
Blockchain Use	Traceability, transparency, and smart contracts	Product authentication, supply chain traceability	Vehicle history tracking, transparency	Drug tracking, anti-counterfeiting
Geographical Coverage	Global (primarily Europe and Asia)	China	Global	China
Technological Innovation	Proof of Authority consensus mechanism, smart contracts, IoT integration	NFC chips integrated with blockchain for product authentication	Blockchain for vehicle history	Blockchain for pharmaceutical transparency
Consumer Engagement	Transparency via QR Codes (COS, Arket), sustainable fashion lines	Consumer trust through verification of wine authenticity	Consumer transparency on vehicle history	Consumer trust through pharmaceutical transparency
Scalability	High scalability in fashion and luxury goods industries	Moderate scalability in luxury goods market	Moderate scalability in automotive industry	Moderate scalability in pharmaceutical industry
Impact on Sustainability	Responsible sourcing, reduced environmental impact in fashion	Reduced counterfeit risk, enhanced trust in luxury goods	Increased sustainability in vehicle manufacturing	Improved pharmaceutical safety, reduced counterfeit risk

3.2.2. VeChain's Competitors

While the primary unit of analysis is the VeChain–Walmart China initiative, alternative initiatives serve as comparative references to highlight similarities and divergences. Accordingly, the criterion of comparative potential was incorporated into the case selection process to ensure that the findings can be meaningfully contextualized within the broader landscape of blockchain applications in global value chains **(4)**.

As previously discussed, VeChain has achieved significant adoption across multiple industries that face acute sustainability challenges. This broad industry applicability, therefore, makes VeChain one of the most versatile blockchain initiatives for addressing sustainability issues across multiple GVCs and distinguishes it from many of its competitors, whose focus tends to be more limited. For instance, IBM Food Trust concentrates primarily on food safety and agricultural supply chain transparency; Everledger specializes in luxury goods such as diamonds, art, and wine, emphasizing provenance and carbon footprint tracking; and Provenance focuses mainly on sustainable consumer goods and fashion supply chains, but without the same cross-sector reach as VeChain. Waltonchain, meanwhile, emphasizes logistics and retail but lacks the established global partnerships and industry penetration of VeChain.

Table 3 compares VeChain with its competitors along key dimensions such as industry focus, sustainability emphasis, technological innovation, scalability, and overall impact on sustainability.

Table 3: Comparative overview of VeChain and competing blockchain initiatives in Global Value Chains

Criteria	VeChain	IBM Food Trust	Everledger	Provenance	Waltonchain
Industry Focus	Supply chain transparency, sustainability (fashion, food, pharma)	Food supply chain (agriculture, meat, dairy, etc.)	Luxury goods, diamonds, wine, art	Sustainable and ethical supply chains (fashion, food, etc.)	Supply chain transparency, logistics, retail
Sustainability Focus	Responsible sourcing, ethical labour,	Food safety, transparency, sustainability in agriculture	Track and trace for ethical sourcing, carbon	Traceability of sustainability practices (eco-	Environmental sustainability, eco-friendly logistics

	Environmental Impact		footprint tracking	friendly products)	
Blockchain Use	Traceability, transparency, smart contracts, IoT integration	Blockchain for food traceability and safety	Blockchain for provenance of products, carbon footprint	Blockchain for product transparency and sustainability	Blockchain for supply chain management and logistics
Key Partnerships	H&M, BMW, Walmart, Bayer, Shanghai DIG	Walmart, Carrefour, Unilever, Nestlé	De Beers, WWF, Everledger Partners	Fairphone, People Tree, Marks & Spencer	Waltonchain Partners, Retailers, and Manufacturers
Geographical Coverage	Global (Europe, Asia, North America)	Global (primarily North America and Europe)	Global (primarily in luxury and jewellery sectors)	Primarily Europe, UK, and Southeast Asia	Primarily China, some expansion into global markets
Technological Innovation	Proof of Authority (PoA) consensus mechanism, smart contracts, IoT integration	Hyperledger Fabric, IoT integration	Smart contracts for provenance and traceability	Smart contracts, IoT integration for sustainable supply chains	Dual-chain solution, IoT integration, DPOS consensus
Consumer Engagement	Transparency via QR codes (COS, Arket), product info on blockchain	QR codes, consumer engagement via traceability	Consumers access product provenance and sustainability data	Product transparency via QR codes and blockchain	Blockchain-enabled transparency, access via app
Scalability	High scalability in fashion, luxury goods, and pharma industries	High scalability in food industry	Moderate scalability in luxury goods and high-value assets	Moderate scalability, primarily focused on specific industries	High scalability in logistics and retail
Integration with Existing Systems	Strong integration with existing supply chain	Integrated with SCM and ERP systems	Partnerships with major diamond and luxury goods companies	Focus on integrating with sustainable brands and their	Integrates with retail systems for SCM

	systems and IoT devices			existing processes	
Impact on Sustainability	Reduced environmental impact, ethical labour practices, transparent sourcing	Improved food safety, reduced waste, ethical sourcing	Improved supply chain transparency, reduced carbon emissions	Increased consumer awareness of sustainability, ethical Sourcing	Increased transparency, reduced environmental footprint in logistics

3.3. Data Collection

The data for this thesis was gathered exclusively from secondary sources. This approach was adopted due to the lack of direct access to primary stakeholders such as Walmart China and VeChain. Furthermore, given the exploratory nature of this case study, the research relied on a variety of sources, including academic literature, corporate publications and whitepapers, industry reports, media coverage, and independent evaluations.

VeChain's three whitepapers were valuable because they help trace the platform's evolution from its initial focus on blockchain adoption (2018), through its emphasis on lowering technical and economic barriers for businesses (2019), to its latest positioning as an enabler of collective sustainability impacts (2023). The progression provides important context for understanding how VeChain frames its mission, technological innovations, and sustainability claims. At the same time, since these documents are self-published, they were treated with caution and cross-checked against the available external reporting to reduce bias.

Furthermore, VeChain and Walmart China's press releases and sustainability disclosures such as their annual and ESG reports offer insights into Walmart's motivation for adopting blockchain, its strategic goals in food safety and traceability, and its commitments to sustainability not only within the Chinese market, but also globally. Additional insights were drawn from PwC and the China Chain-Store & Franchise Association (CCFA), whose statements highlight their contributions as implementation partners and regulatory overseers in the initiative.

Finally, academic literature was used to provide the conceptual foundations for blockchain's role in supply chains and sustainability, thereby supporting the analysis of the initiative. A key limitation in the research process, however, was the absence of specific metric data from

Walmart China. In such cases, data from Walmart's global operations was analysed, and reasoned assumptions were made to approximate insights for the Chinese division. Together, all sources allowed the study not only to reconstruct the initiative but also to examine it from technological, organizational, regulatory, and consumer perspectives.

3.4. Analytical Framework

The collected data is analysed using thematic analysis, structured around the research questions and sustainability dimensions outlined in the introduction. The framework integrates technological, organizational, and sustainability dimensions, enabling a holistic understanding of the initiative and its broader implications. Four thematic clusters guide the analysis.

3.4.1. Conceptual Lens: Blockchain for Transparency & Traceability

Blockchain technology is becoming more recognized for its potential to enhance transparency, traceability, and accountability within supply chains, thus, supporting key sustainability objectives (Saberi et al., 2019; Tian, 2016). Its core features – immutability, decentralization, and smart contracts, enable the reliable tracking of products and processes and ensure that information is accurate and tamper-proof. In this study, the focus lies on how VeChain's blockchain platform operationalizes these features within the Walmart China collaboration, providing real-time visibility and verifiable data across the food supply chain.

3.4.2. Analytical Dimensions

The study is structured around three interrelated dimensions: technological, organizational, and sustainability impact. The technological dimension focuses on the architecture and capabilities of VeChain's blockchain platform, assessing how features such as the Proof of Authority consensus mechanism, IoT integration, and smart contracts enable secure, transparent, and efficient tracking across the supply chain. The organizational dimension examines Walmart China's adoption and integration of blockchain within its operational processes, including governance structures, stakeholder collaboration, and coordination with suppliers and external partners. Finally, the sustainability and impact dimension evaluate the initiative's outcomes in terms of environmental, social, and ethical performance, analysing how blockchain adoption contributes to transparency, resource efficiency, ethical labour practices, and consumer trust across the food supply chain. This dimension is further structured into three focus areas: environmental sustainability, which examines the impact of blockchain on reducing waste and promoting circular economy practices; social and ethical practices, which considers its role in strengthening labour rights and ethical sourcing; and economic considerations, including efficiency gains, cost implications, and value creation across the supply chain. The challenges and limitations of the initiative, such as scalability, regulatory constraints, and industry resistance, were also taken into account.

3.5. Ethical Considerations

Although this study relies exclusively on secondary data, ethical considerations remain a central factor to ensure the credibility and responsible use of information in this thesis. The research adheres to principles of transparency, accuracy, and objectivity when collecting, analysing, and presenting data from all sources. Data accuracy and verification were prioritized by cross-referencing VeChain and Walmart China's self-reported claims by comparing different external sources whenever was possible. Moreover, no proprietary or sensitive data from Walmart China, VeChain, or associated partners were accessed, ensuring that the study does not compromise stakeholder privacy or violate any non-disclosure agreements. The research integrity and acknowledgment were maintained by properly citing all sources and avoiding any form of misrepresentation. The study emphasizes transparency in methodology, including the limitations of relying on secondary data, assumptions made in the absence of primary metrics, and potential biases in corporate reporting. Finally, ethical responsibility in interpretation was considered by critically reflecting on the broader implications of blockchain adoption in global value chains, including potential social, environmental, and economic consequences. This ensures that the analysis not only evaluates corporate initiatives but also considers their impact on stakeholders and sustainability outcomes within a global context.

4. Analysis and Discussion

4.1. Background: VeChain and Walmart China

4.1.1. Introduction of VeChain

VeChain is a blockchain ecosystem that was originally launched in Singapore in 2015 by Sunny Lu, the former CIO of Louis Vuitton China, and Jay Zhang, and is currently headquartered in San Marino. Initially, its mission was to advance the creation of digital ecosystems that promote global sustainability and drive digital transformation by supporting blockchain-based business applications offering real economic and social value (VeChain, n.d.-a; VeChain, 2018). While in its second whitepaper from 2019, VeChain positions itself as an enabler that aims to lower the barrier to blockchain adoption and empower businesses, governments, and individuals to effortlessly create valuable transactions within collaborative ecosystems (VeChain, 2019), in the third and latest whitepaper, VeChain states that its mission is to 'multiply individual impact to unleash their collective potential for sustainability' (VeChain, 2023, p. 7). This progression reveals an intent to broaden the company's impact beyond just enterprise use cases to include societal and environmental contributions.

VeChain is a decentralized infrastructure that operates publicly while being strategically driven by a steering committee and the VeChain Foundation (VeChain, n.d.-b). Its public blockchain called VeChainThor, is built on certain technical foundations of the Ethereum blockchain. Designed for mass adoption, it offers innovative technical solutions that are powered by a unique governance framework and dual-token economic model. Since its launch in 2018, VeChainThor has reportedly maintained continuous operation of 100 % uptime, producing new blocks approximately every 10 seconds (VeChain, n.d.-c.). The network is also promoted as highly energy-efficient, consuming just 0.04% of the energy used by other blockchains. It is important to note, however, that these claims are self-reported and difficult to independently verify.

4.1.2. VeChainThor's Consensus Mechanism: Proof of Authority

VeChainThor uses a Proof of Authority consensus algorithm, powered by 101 Authority Masternodes responsible for producing new blocks and validating transactions by adding them to the blockchain (VeChain, n.d.-b). This number of validators is significantly lower compared to other networks like Ethereum (PoS) or Bitcoin (PoW), which typically involve thousands of nodes. Therefore, since the Authority Masternodes are pre-approved and trusted, VeChainThor can reach consensus with minimal communication between the nodes. However, VeChainThor is not fully decentralized. In order to become an Authority Masternode, an individual or entity must voluntarily disclose their identity to the VeChain Foundation and undergo a strict know-your-customer (KYC) process before being selected. This requirement means that only trusted entities are allowed to validate blocks, and only blocks produced by an Authority Masternode will be considered valid by the VeChainThor blockchain (VeChain, n.d.-b). While this aligns with regulatory requirements and enhances trustworthiness, it also means that only those with the resources and willingness to comply with such processes can become validators.

De Filippi and Wright (2018) highlight that blockchain and smart contracts enable certain groups to establish their own governance structures. Such selective participation creates a barrier to entry, effectively centralizing control within a limited set of entities or actors. Consensus mechanisms like the Proof of Authority one that VeChain implements, while legally compliant, can conflict with the main ethos of blockchain – decentralization, by restricting who can participate in the governance of the blockchain.

4.1.3. VeChain's Token Economy and Multi-Clause Transaction Capabilities

VeChain operates on an innovative dual-token model, consisting of VET (VeChain Token) and VTHO (VeChainThor Energy Token). Through its numerous partnerships, VeChain identified that the fluctuating nature of cryptocurrency prices creates an obstacle to the widespread adoption of blockchain technology, due to unpredictable costs. Therefore, VeChain introduced the dual-token model as a potential solution to address this challenge (VeChain, n.d.-d). VET serves as a long-term store of value and has a fixed supply of around 86 billion tokens which have already been minted (VeChain, n.d.-c; VeChain, n.d.-d). VTHO, on the other hand, is used to pay for transaction fees and smart contract executions. It functions as a native currency to pay for the cost of computation on the blockchain. This ensures that the transaction costs are predictable and stable, separate from the fluctuating value of VET.

Moreover, VeChainThor supports Multi-Clause Transactions (MCT), meaning that multiple clauses perform a separate action within a single transaction (e.g., token transfers, smart contract executions, or data updates), thus significantly improving operational efficiency (VeChain, n.d.-c). This is important for VeChain's collaboration with Walmart China since various supply chain events need to be recorded from multiple stakeholders, and MCT enables these actions to be processed simultaneously within one transaction.

4.1.4. Introduction of Walmart China

Walmart is an omni-channel retailer driven by people and powered by technology, with a mission to help customers save money and live better, offering the flexibility to shop in stores, online, and access other services anytime and anywhere (Walmart Inc, 2024). Founded in 1962 by Sam Walton in Arkansas, United States, Walmart Inc. has grown into one of the world's largest retail corporations. Over the past six decades, the company has expanded its operations to include more than 10,750 physical stores and numerous e-commerce platforms across 19 countries, employing approximately 2.1 million people globally (Walmart China, n.d.-f).

Walmart China is a subsidiary of Walmart Inc., which has established itself as a leading player in the Chinese retail market, with a total of 336 retail units of Walmart Supercenter and Sam's Club across the country (Walmart International, 2025). Since its opening in 1996 Walmart has made significant strides in adapting its business model to the needs and preferences of the Chinese consumer, partly by employing a predominantly Chinese workforce, which accounts for 99.9% of its total employees in the country. According to their most recent goals, Walmart China is not only committed to sustainability but also aims to become a 'regenerative' company, focusing on restoring and enhancing both the environment and the communities in which they operate (Walmart International, 2025).

In recent years, Walmart China has focused on using digital transformation to improve its operations, enhance customer experiences, and promote transparency in its supply chain. This drive for transparency is largely driven by the increasing consumer demand for traceable and ethically sourced products, particularly in the food and grocery sectors. With concerns over food safety and quality, Walmart China has taken proactive steps to ensure that consumers can trace the origin and journey of their purchases. In this context, blockchain technology has emerged as a key tool in Walmart China's efforts to enhance supply chain transparency, reduce inefficiencies, and build consumer trust.

Walmart China's partnership with VeChain marks a critical step in this journey. Both companies aim to revolutionize how product information is tracked and shared within supply chains. The incorporation of VeChain's blockchain solutions supports Walmart China on its mission to provide real-time, immutable data on product origins, quality, and handling processes, and aligns with Walmart's broader commitment to sustainability, efficiency, and consumer empowerment through the access to reliable, transparent, and traceable product information.

4.1.5. Research Significance

This study is significant both academically and practically. Academically, it contributes to the limited but growing body of literature that analyses the intersection between blockchain technology and sustainability in global value chains. By conducting a qualitative case study of VeChain and Walmart China, this research aims to deepen the understanding of how digital technologies can promote transparency, reduce environmental impact, and support ethical practices in supply chains.

Practically, this collaboration reflects how blockchain can serve not just as a financial ledger, but as a transformative infrastructure for data governance, stakeholder trust, and long-term ESG performance. The insights from this study may assist policymakers, supply chain managers, and sustainability officers in understanding the real-world potential of blockchain solutions. It offers a blueprint for how large enterprises can digitize and decarbonize GVCs using modular blockchain tools. The study also illustrates how companies like Walmart are combining blockchain with IoT to build resilient, transparent, and sustainable supply systems, capable of withstanding global shocks, as well as how they may operationalize newer technologies and offer a blueprint for scalable and effective supply chain innovations that address critical global challenges such as food safety, waste reduction, and responsible sourcing.

4.2. Blockchain Implementation: The VeChain-Walmart China Blockchain Initiative

4.2.1. The Case of VeChain and Walmart China

The COVID-19 pandemic has intensified the urgency for food companies to build more resilient and transparent supply chains to adapt to the challenges of an increasingly dynamic marketplace. The outbreak and the following lockdown disrupted global value chains due to transport restrictions, work shutdown and maintaining the social distancing, but specifically affected the food industry, where perishable items demand fast, transparent, and precise logistics management (Kumar & Kumar Singh, 2022). The physical verification and certification of food items became very difficult due to the restrictions on movement, delays at borders, and the closure of inspection facilities. As a result, many food companies faced challenges in maintaining the quality and safety standards of their products. VeChain had just launched its blockchain-powered Food Safety Solution, built on the VeChain ToolChain™ platform, a comprehensive Blockchain-as-a-Service (BaaS) offering ready for the market.

The collaboration between VeChain and Walmart China demonstrates several ways of the implications of blockchain technology in addressing sustainability challenges across different dimensions of the supply chain. BaaS is a cloud-based service that allows businesses to build, host, and use their own blockchain applications without having to create and manage the underlying infrastructure (Li et al., 2022). Through the adoption of VeChain ToolChain™, a specific implementation of the BaaS model, Walmart China has created a more resilient supply chain for its food products, which enables real-time tracking and verification of food items from source to store by scanning a QR code on the product packaging.

According to VeChain, its solution enables the fastest deployment of blockchain technology in the food sector compared to any other platform in the industry (VeChain Foundation, 2020). This claim should be approached with caution, as it is reported by VeChain and lacks independent, objective verification. Although VeChain's established use cases, such as the one with Walmart China, suggest relatively fast implementation, other platforms like e.g., TE-FOOD have been operational for years. Therefore, it is reasonable to question whether these long-established solutions might offer comparable or even greater deployment speed.

The VeChain ToolChain™ powered Food Safety Solution offers full lifecycle traceability for supply chains, from farm to retail and the customer's hand. This end-to-end traceability helps optimize logistics and inventory management, reduces overproduction and energy consumption, and also supports ethical sourcing and labour practices, while helping organizations to build more agile and resilient supply chains that can adapt to future disruptions (Malik et al., 2021).

4.2.2. VeChain ToolChain™'s Mechanism: A Strategic BaaS Model for Sustainable Food Supply Chains

The VeChain ToolChain™ represents a modular and user-friendly blockchain ecosystem that integrates coherently with IoT devices, mobile interfaces, and enterprise resource planning (ERP) systems. ToolChain™ is structured across several service layers (see Figure 3). The first layer is the BaaS Core Services, which provide essential features such as blockchain data storage and IoT integrations, building the foundational support for the ecosystem. Next, the Software as a Service (SaaS) Modules are tailored for specific use cases, including food safety, sustainability, and asset certification, offering customizable solutions for various industries. Additionally, the Platform as a Service (PaaS) Tools enable users to customize applications, giving them the flexibility to adapt solutions according to their needs. Finally, the Business Applications are pre-designed solutions that can be deployed directly, providing ready-to-use applications for businesses.

This layered architecture allows businesses, in this case Walmart, to access blockchain benefits such as data immutability, smart contract automation, and end-to-end traceability, all without the need of deep in-house blockchain expertise.

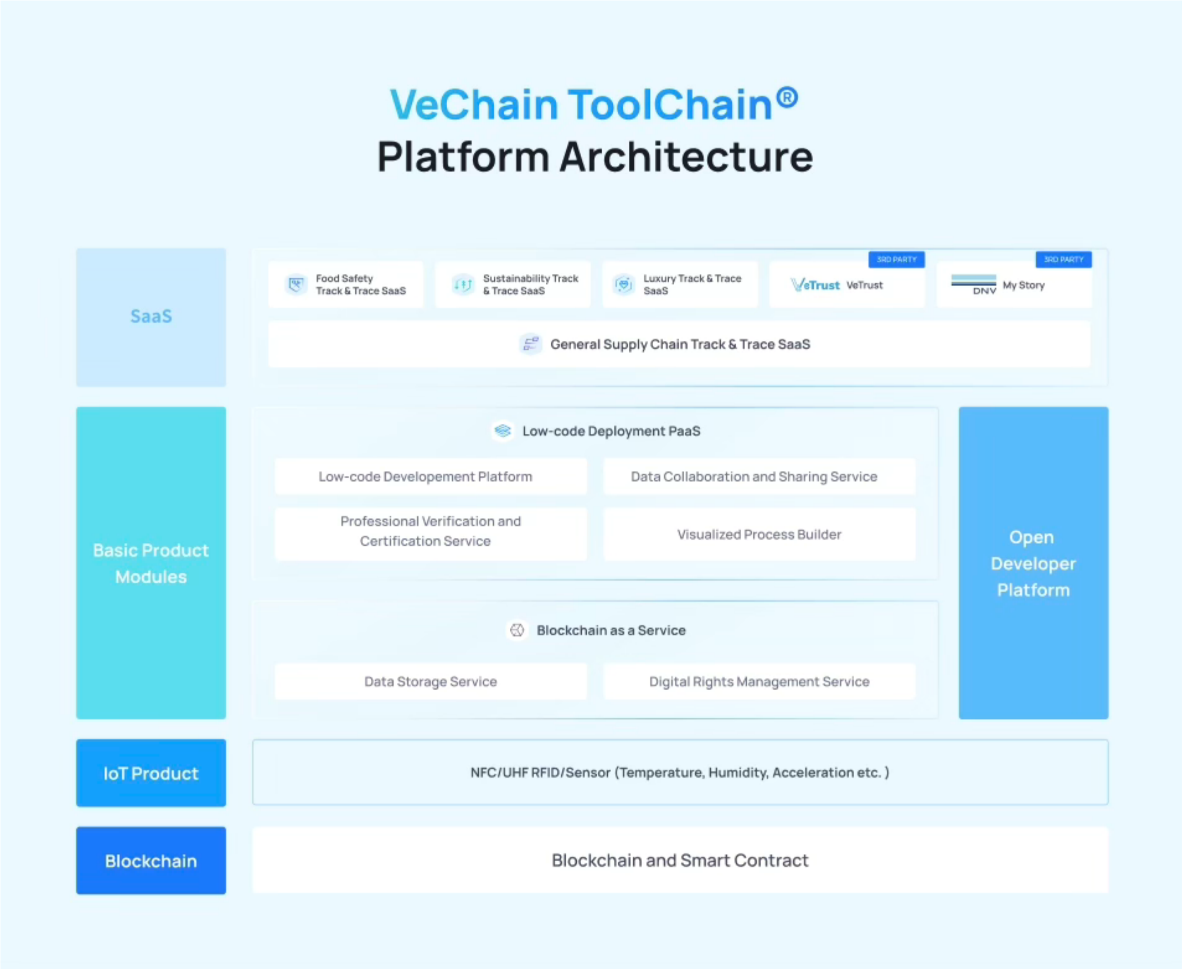

Figure 3: VeChain ToolChain™ platform architecture (VeChain)

Table 4 maps VeChain ToolChain™'s service layers to their potential sustainability benefits in the Walmart China case and highlights how technological functions align with environmental and operational outcomes. It links each layer with specific sustainability gains, such as waste reduction, improved traceability, and supply chain transparency. Furthermore, the table demonstrates how blockchain-enabled modular architectures can address both logistical inefficiencies and environmental challenges. This mapping illustrates the scalability of the ToolChain™ framework and suggests that similar benefits could be replicated across other industries and geographical contexts.

Table 4: Mapping of VeChain ToolChain™ layers to sustainability benefits

ToolChain Layer	Function (as described)	Sustainability Benefit
BaaS Core Services	Blockchain data storage, IoT integration	Real-time traceability → reduced waste & spoilage
SaaS Modules	Food safety, sustainability, asset certification	Transparency → improved consumer trust
PaaS Tools	Customization of applications	Flexibility → lower adoption barriers
Business Applications	Pre-designed solutions for direct deployment	Rapid scaling → broader sustainability impact

4.2.3. Walmart China's Deployment of VeChain ToolChain™

On June 25, 2019, Walmart China, in a strategic partnership with the China Chain-Store & Franchise Association, PwC, Inner Mongolia Kerchin Co., Ltd., and VeChain, officially announced the launch of the Walmart China Blockchain Traceability Platform at the 2019 National Food Safety Promotion Week Traceability System Construction Seminar in Beijing. Built on the VeChainThor Blockchain, the Platform aims to enhance food safety, transparency, and supply chain efficiency by tracking and authenticating products via VeChain's ToolChain™ (Walmart China, 2019). The initial phase of the Walmart China Blockchain Traceability Platform's deployment included 23 product lines, already tested and launched, encompassing categories such as fresh meat, rice, mushrooms, and cooking oil. Walmart China planned to expand this to over 100 product lines by the end of 2019, covering more than 10 product categories. The goal was to have traceable fresh meat account for 50% of total packaged fresh meat sales, traceable vegetables for 40% of packaged vegetable sales, and traceable seafood for 12.5% of seafood sales by the end of 2020 (PR Newswire, 2019).

Each product integrated into the platform was assigned a unique QR code. Consumers could scan these codes using their smartphones to access detailed information about the product, including information about the origin of the product (farm and batch details), processing records, the locations the product has passed through during its journey to the store, as well as details about the transportation and handling of the product, and finally the inspection records, including results from quality checks and safety inspections done at different stages.

The collaboration brought together multiple stakeholders from different industries. PwC acted as a strategic advisor and implementation facilitator, guiding Walmart China on how to effectively apply blockchain technology via VeChain ToolChain™ within its supply chain. Elton Yeung, Strategy and Innovation Leader at PwC Mainland China and Hong Kong, emphasized PwC's commitment to building consumer trust through technological innovation. In the official press release he stated:

"PwC's mission is 'building trust and solving important problems', which is the top priority of PwC in providing professional services and making business decisions. In the face of food safety, how to build consumer trust is a problem that PwC, our clients and partners have been trying to solve. We believe that Walmart's Blockchain Traceability System will be an excellent example of blockchain technology applied in the retail industry, helping to improve food safety and quality management, and providing a strong guarantee for building consumer trust." (PR Newswire, 2019).

The moderating role of PwC was further supported by the CCFA, which contributed through its supportive function and alignment with regulatory standards in the Walmart China Blockchain Traceability Platform initiative. With over 1400 enterprise members and 460,000 outlets, including domestic & foreign-invested retailers, franchisers, suppliers, and relevant organizations, CCFA is the official representative of retailing & franchise industry in China (Global OMP, 2025). Though its endorsement of VeChain's partnership with Walmart China and ensuring its consistency with national regulatory frameworks, CCFA helped legitimize the use of blockchain technology in retail and encouraged broader adoption among industry stakeholders. Its involvement not only reinforced PwC's efforts to guide and coordinate the initiative but also provided a foundation for scaling the solution across China's retail sector, as it signalled the credibility of blockchain-based traceability to the wider retail industry and encouraged other major retailers to consider similar technological upgrades.

Moreover, one of the main producers involved in the collaboration, and the key beef supplier for the initiative, was Inner Mongolia Kerchin Co., Ltd. Kerchin's participation was particularly significant given the sensitivity of meat products to food safety concerns and the heightened demand for transparency in their supply chains. Kerchin served as an early example of how suppliers could integrate with the VeChain ToolChain™ system to provide real-time, verifiable information about their products. This included the animal's origin, processing details, logistics records, and inspection data. During the official launch conference in 2019 Pei Liang, President of the China Chain Store & Franchise Association, said:

"It is hoped that more retail companies can learn and draw on these new technologies, make good use of blockchain and other new Internet technologies, empower retail with technology, provide stronger guarantees for building trusted consumption, and make the lives of Chinese consumers more secure, more convenient, and healthier." (Walmart China, 2019).

As the platform aimed to scale beyond beef to categories, Walmart China's collaboration with a growing network of producers, in alignment with CCFA guidelines and PwC's strategic oversight, laid the groundwork for a more transparent and secure food retail ecosystem.

Other suppliers of Walmart China that attended the 2019 National Food Safety Promotion Week Traceability System Construction Seminar on June 25th, 2019 were Wilmar International Holdings Limited, China Resources Ng Fung Holdings Limited, COFCO Fortune Food Marketing Co., Ltd. and Huamei Group. The discussion focused on the implementation of responsibilities among all stakeholders, the integration of technological innovations, and the assurance of quality and safety in food and edible agricultural products. With their efforts, they aimed to enhance consumer confidence and satisfaction, while also supporting the upgrading of consumption patterns (Walmart China, 2019).

4.3. Addressing Sustainability Issues Through Blockchain

Although the original goal of the collaboration was to develop an exclusive food safety traceability platform based on blockchain technology that uses the decentralized and tamper-resistant nature of blockchain to improve the transparency of product information and thereby strengthen consumer trust (Walmart China, 2019), the initiative has also generated several other beneficial outcomes regarding sustainability issues across GVCs. These include addressing longstanding challenges in supply chain management, supporting regulatory compliance, and enabling more sustainable sourcing practices.

4.3.1. Environmental Benefits of the VeChain–Walmart China Collaboration

Waste Reduction & Operational Efficiency

In 2015, Chinese authorities confiscated over 100,000 tons of smuggled frozen meat, including pork, beef, and chicken, some of which was reportedly more than 40 years old, dating back to the 1970s. The meat, valued at approximately £300 million (3 billion yuan; $483 million), was seized in a nationwide crackdown in Hunan, and was found to have been thawed during transportation and then subsequently refrozen (BBC News, 2015). This incident raised two critical issues for the food supply chain industry: food fraud and the lack of an effective traceability system.

For perishable products, it is essential to coordinate activities from the farm to the end-user effectively and maintain a smooth flow of information throughout the supply chain to preserve freshness, ensure quality, and prevent deterioration in the marketplace (Collart & Canales, 2022). Traditional food safety systems largely depend on process controls and the assumed social responsibility of businesses. However, they often lack the ability to effectively track, trace, record, and pinpoint the location of food within the supply chain, which makes it challenging to detect and address issues when they arise (VeChain, 2018).

In its 2019 ESG Report, Walmart acknowledged that a major challenge in waste management is the lack of granular data and insights into the drivers of waste across the supply chain (Walmart Inc., 2019b). One of the responses for this issue was the collaboration between VeChain and Walmart China, which offered the benefit of waste reduction across the food supply chains by improving inventory management and minimizing overstocking and spoilage.

In its 2022 ESG Summary, the company disclosed that it had managed to divert 78% of waste globally in 2021 (Walmart Inc., 2022). Although the report does not specify the exact contribution of Walmart China to this figure, it is reasonable to assume that the department accounted for a significant portion, given the scale of the Chinese operations. Through the integration of blockchain technology the company gained the ability to trace food products in real time from their origin to the store shelves. As a result, fewer resources were wasted on the production, storage, and transportation of goods that might have otherwise spoiled or gone unsold, which has not only prevented financial and food losses but has also helped avoid unnecessary energy consumption linked to wasted production.

Despite these benefits however, several challenges remain. Blockchain only records the data that was entered, so inaccurate or incomplete supplier data could compromise traceability. Moreover, not all suppliers may have the resources or technical capacity to implement blockchain-based tracking. This limits the previously mentioned operational gains.

Logistics & Transportation Optimization

Food safety and waste reduction are closely linked to efficiency of logistics, which also relies heavily on accurate, real-time data across the entire supply chain for optimal performance (Pal & Kant, 2020). The process of cold chain logistics, which refers to the transportation and storage of temperature-sensitive products, is particularly vulnerable to inefficiencies. It could be improved through blockchain technology combined with IoT sensors, which allow real-time data collection and transmission (Wu et al., 2021). To ensure quality, products must be stored at the proper temperature, delivered before expiration, and matched with actual demand.

In 2016, Walmart’s Vice President of Food Safety tasked his team to trace the origin of a package of sliced mangoes. Although the necessary data existed within the company’s system, it took the team 6 days, 18 hours, and 26 minutes to identify the source (Walmart Global Tech, 2021). Such examples highlight the challenges posed by the lack of integrated tracking. They delay responsiveness, and thus, hinder improvements in logistics. Walmart has also highlighted the complexity of commodity supply chains in its 2019 ESG Report, referring to the complex processes involved in producing, transporting, and delivering raw materials from their origin to the end user, as a significant barrier to gaining comprehensive data and insights (Walmart Inc., 2019b).

Blockchain technology offers a powerful solution. Since it improves traceability by recording every transaction or movement of goods, every stakeholder can see where the product is, where it’s been, and who handled it (Collart & Canales, 2022). Through their partnership with IBM, Walmart managed to reduce the time required to trace the origin of mangoes in U.S. stores, which previously took nearly seven days, to just 2.2 seconds (Walmart Global Tech, 2021). This advancement laid the foundation for improving traceability and transparency.

With over 10.500 stores in 24 different countries in 2022 (Walmart Inc., 2022), Walmart Inc. was facing the challenge of managing one of the largest and most complex retail supply chains in the world. By adopting region-specific blockchain solutions – IBM in the U.S. and VeChain in China, the company has demonstrated the scalability and adaptability of this technology to diverse regulatory, infrastructural, and consumer contexts. The collaborations are a great example of how blockchain can not only accelerate traceability but also transform logistics into a data-driven, sustainable, and more efficient system across global operations.

Integrating blockchain with existing logistics and cold chain systems, however, requires significant investment and coordination among suppliers, logistics providers, and retailers. Thus, while the benefits of blockchain in logistics are substantial, the full realization of these advantages depends on overcoming barriers of cost, technological readiness, and consistent stakeholder participation.

Carbon Footprint Reduction

In 2018, 90 % of Walmart's total emissions originated from its value chain (Walmart Inc., 2018). That year, the estimated Scope 1 emissions, which are the direct greenhouse gas (GHG) emissions that come from sources owned or controlled by the company, totalled 6.1 million metric tons of CO_2e. Meanwhile, Scope 2 emissions, or the indirect emissions from purchased energy, were estimated at 12 million metric tons of CO_2e (Walmart Inc., 2019a). However, the company also acknowledged in the 2019 CPD Climate Submission that a portion of its Scope 1 and 2 emissions were not included in the reported figures, indicating that the actual totals may be even higher. Furthermore, their estimated Scope 3 emissions alone amounted to over 143.2 million metric tons of CO_2e (Walmart Inc., 2019a).

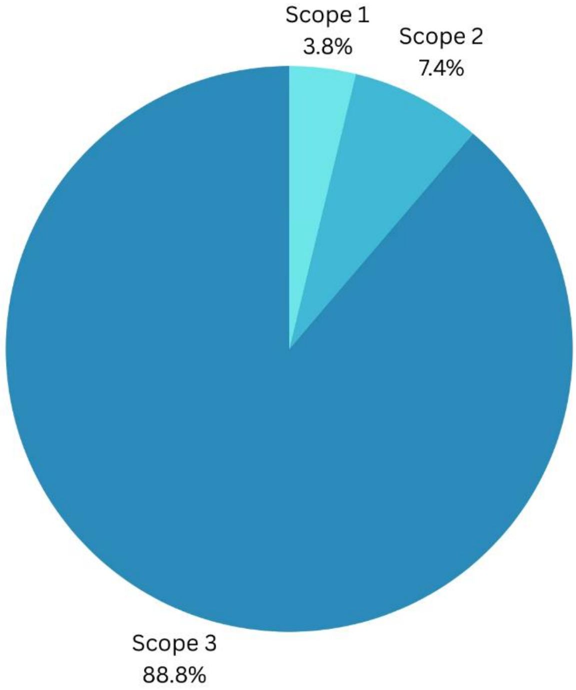

Figure 4: Walmart's greenhouse gas emissions by scope (Scope 1, 2, and 3) in 2018

This figure exceeds Walmart's Scope 1 and 2 combined, as seen on Figure 2, and also reveals that the vast majority of Walmart's environmental impact did not stem from its own operations, such as stores, warehouses, or company-owned vehicles, but rather from indirect activities across its supply chain. These include emissions from the production of goods by third-party suppliers, the transportation of products by external logistics providers, and even the usage and disposal of products by consumers.

This category of emissions, Scope 3, is typically the most difficult to monitor and control, yet it often represents the largest share of a company's overall carbon footprint (Hettler & Graf-Vlachy, 2024). For a retailer of Walmart's scale, with thousands of suppliers and a global network of distribution and manufacturing partners, the environmental consequences are profound.

Considering that a substantial portion of Walmart's global supply chain is based in China, and that many of its products are sourced from there, it is likely that a significant share of these estimated emissions originates from Walmart's operations and suppliers in China.

In response, Walmart launched strategic initiatives such as Project Gigaton, a major effort to engage suppliers in reducing emissions, and the 'Zero Waste Goal,' which aimed to achieve zero operational waste in key markets like the U.S., Canada, and Japan by 2025

(Walmart Inc., 2018). Additionally, Walmart supported the continuation of its blockchain efforts in China, building on earlier collaborations that started in 2017, this time through the collaboration with VeChain. These commitments were expected to reduce CO_2e emissions by allowing the company to identify inefficiencies through the unique ID of products on the VeChainThor blockchain, such as e.g., excessive transportation steps, energy-intensive suppliers, and help optimize routes and sourcing, reducing transportation-related (Scope 3) emissions. Moreover, through the immutable record of supplier practices Walmart could favour low-carbon suppliers and pressure others to adopt better, more sustainable practices.

When analysing Walmart's 2021 CDP Climate Submission, which reports data for the year of 2020, one year post the collaboration with VeChain, the company states a total of 7.2 million metric tons of Scope 1 CO_2e emissions, 11 million metric tons of Scope 2 CO_2e emissions, and 130.2 million metric tons of Scope 3 CO_2e emissions (Walmart Inc., 2021a). The reported figures in Walmart's 2021 CDP Climate Submission reveal several

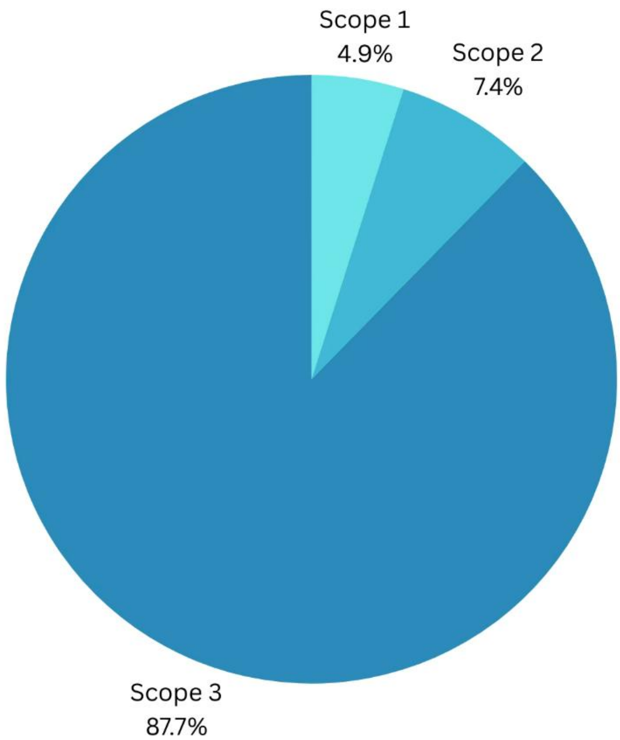

Figure 5: Walmart's greenhouse gas emissions by scope (Scope 1, 2, and 3) in 2020

notable trends. While Scope 1 emissions increased slightly from 6.1 to 7.2 million metric tons of CO_2e – potentially due to expanded operations or improved reporting accuracy, Scope 2 emissions saw a modest decline from 12 million to 11 million metric tons, suggesting some progress in energy efficiency or a shift toward cleaner electricity sources. Most significantly, Scope 3 emissions decreased from 143.2 million to 130.2 million metric tons of CO_2e, marking a reduction of approximately 9%.

It is important to note that the specific share of emissions attributable to Walmart's operations or suppliers in China cannot be precisely determined, as the company does not disclose country-level emission data. However, given the scale of Walmart's sourcing and manufacturing activities in China, it is reasonable to assume that a significant portion of its reported emissions, particularly Scope 3, originates from its Chinese supply chain. Moreover, while the reduction should not be solely attributed to the VeChain blockchain collaboration, it most likely has played a role in improving supply chain transparency and efficiency.

4.3.2. Economic sustainability

Some of the most tangible outcomes of the partnership between Walmart China and VeChain are of economic nature. The collaboration demonstrates how technological innovation can boost economic sustainability by streamlining supply chain operations. Previously discussed challenges, such as inventory discrepancies, product spoilage, and inefficiencies in distribution, can be effectively addressed through blockchain integration. As a result, warehousing and transportation costs are reduced, while the risks associated with product recalls and supply chain fraud are also significantly diminished.

Enhancing Cost Efficiency Through Supply Chain Optimization

One example of economic sustainability is the improvement of inventory management through the integration of advanced technologies such as blockchain. More accurate demand forecasting allows companies to align their inventory levels more closely with actual market needs. This minimizes the risk of overstocking, which ties up capital and result in unsold or expired goods. Maintaining optimal inventory levels helps businesses reduce waste, lower storage costs, and allocate resources more efficiently (Albayrak Ünal et al., 2023).

Since 2020, Walmart China has maintained strong sales growth, as reflected in its division's total revenue and net sales reports. At the 2023 Supplier Summit, Walmart China stated: "Through digital transformation and strengthening talent, organization and culture, Walmart has solidified its foundation to better serve customers and members" (Walmart China, 2023). This may be translated to a positive correlation between the company's performance and its broader digital transformation strategy.

Walmart's strong economic foundation not only enhances internal operations but also allows the company to invest in broader sustainability initiatives. These include not only substantial efforts toward environmental impact – e.g., Project Gigatron, use of renewable energy, aiming for 100 % by 2035, but also social impact - disaster relief efforts, as well as Walmart Foundation's donations towards education, food security, and DEI programs (Walmart Inc., 2021b).

Stronger Supplier Relationships

Moreover, strengthening supplier relationships is another outcome of the collaborative partnerships advanced through Walmart's digital transformation efforts. This is an important element of economic sustainability, as it promotes mutual growth, transparency, and long-term value creation. Strong supplier relationships also provide a competitive advantage for companies that actively invest in the development of their suppliers. Such efforts lead to significant improvements in delivery quality, operational flexibility, and cost efficiency, while also helping reduce inventory levels and associated expenses (Bai et al., 2021).

In its latest annual report, Walmart highlights that their partnerships allow suppliers to efficiently sell large volumes of their products, and in turn enable Walmart to pass on low prices to its customers (Walmart Inc., 2025). This demonstrates a mutually beneficial relationship that not only strengthens supply chain resilience, but also supports long-term business viability. Additionally, Walmart has highlighted its collaborative approach with suppliers as part of its broader sustainability goals, for example in its efforts to avoid one gigaton of greenhouse gas emissions by 2030 (Walmart Inc., 2019b).

Through blockchain traceability, Walmart integrates more than 100,000 suppliers closely into the company's quality and sustainability frameworks, aligning operational practices with its environmental goals. VeChain's additional help with end-to-end product traceability has enhanced suppliers' willingness and capacity to adopt sustainable practices, as well as their willingness to adopt transparent labelling, participate in the Sustainability Index, and cooperate by reporting on avoided CO_2 emissions.

4.3.3. Social sustainability and ethical sourcing

Walmart Inc. places a lot of attention on the social and ethical aspects of its development strategy. Social sustainability in retail includes creating healthy, diverse and equitable communities (Khan, et al., 2021a), ensuring protecting human rights, and supporting fair labour and ethical sourcing practices (Toussaint et al., 2021). In all its reports, Walmart outlines initiatives aimed at improving diversity, equity, inclusion, and workers' overall well-being, with a strong emphasis on creating safe working conditions, fair compensation, and opportunities for career development across all levels of the organization. However, the company identifies the complexity of supply chains as one of their main social challenges (Walmart Inc., 2019b), likely due to the difficulty of effectively monitoring and enforcing its social responsibility commitments across numerous suppliers and regions. Moreover, emerging trends in the global political landscape, the expanding scope of both international and local laws and regulations (e.g., due diligence obligations and modern slavery acts), and growing calls from consumers, stakeholders, and civil society for greater transparency have been further identified as great challenges by Walmart and have additionally intensified the pressure on the company to ensure responsible practices across their entire supply chain (Walmart Inc., 2019b).

Beyond environmental and economic gains, the partnership between VeChain and Walmart China has also significantly advanced social sustainability. The ability to track supplier behaviour and product origins in real time has reduced the likelihood that unethical labour practices or regulatory violations go undetected. In FY2022 alone, Walmart assessed approximately 14,000 third-party audits of facilities producing products for its stores - an effort that is relevant to company's pursuit of more efficient and transparent supply chain management, as well as managed more than 700 cases involving allegations of supply chain misconduct (Walmart Inc., 2022), which may have included labour rights violations or human rights abuses. While these figures represent global operations, the impact of initiatives like the VeChain partnership are imperative for traceability and accountability in key markets such as China, where supply chain complexity and ethical risks can be especially pronounced.

Worker Rights and Ethical Labour Visibility

The protection of worker rights remains a central pillar of corporate social responsibility. Walmart has actively collaborated with stakeholders to address forced labour and exploitative practices in global supply chains, with a particular focus on promoting responsible recruitment as a standard business practice among employers worldwide (Walmart Inc., 2022). In Walmart's 2020 Environmental, Social and Governance Report they state they "are collaborating with their peers and key stakeholders to strengthen and standardize expectations to drive improvement across supply chains – both within our company and beyond it" with more than 14,500 third-party audit reports, only 24 % of which received a green rating, as seen on Figure 6 (Walmart Inc., p. 67, p. 69, 2020).

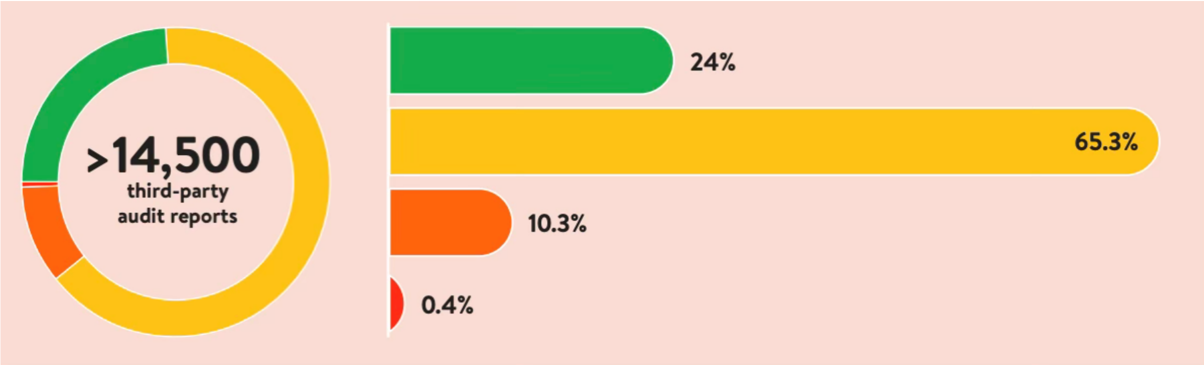

Figure 6: Social compliance audits (Walmart Inc., 2020)

Moreover, the company's 'Human Rights Statement' serves as a foundational framework for its approach to human rights, including key aspects like fair compensation, a safe and secure work environment, diversity and inclusion, as well as the prevention of forced and underage labour, and human trafficking (Walmart Inc., 2022).

Investing in technological partnerships has supported these commitments, particularly in high-risk markets such as China. Prior reports and press releases of Walmart have tended to place less emphasis on social issues such as labour rights enforcement and ethical recruitment practices, and more on the environmental or economic dimensions of sustainability. As illustrated in Walmart's 2019 ESG report (see Figure 7), while stakeholder concerns include broad social topics like job stability, inclusion, and community support, more complex labour issues, such as forced labour prevention and ethical recruitment, are absent.

STAKEHOLDERS & THEIR ESG PRIORITIES		
Associates	• Job stability and mobility, including wages, benefits, training and promotions • Inclusive workplace	• Community: local giving, hunger and disaster relief
Customer	• Everyday low price: affordable food and products • Associate training, wages and benefits • Healthy, environmentally friendly products	• Local sourcing and responsible sourcing • Community: hunger, disaster relief and veterans • Transparency
Suppliers	• Growing their business • Understanding Walmart's standards • Responsible sourcing • Emissions, deforestation, water and waste	• Packaging • Safer and healthier products • Opportunity for diverse suppliers
Communities	• Local economic impact: taxes, jobs, sourcing and affordable products • Support for local organizations • Disaster response and resilience	• Food security • Emissions, waste and natural capital
Shareholders & ESG research analysts	• Enterprise strategy and long-term stock performance • Environment: climate and waste • Social: associate training and wages, responsible sourcing	• Governance: ethics and compliance, and executive compensation • Regulatory and trade environment
NGOs, grantees & advisory councils	• Issues vary by group • Associate opportunity • Inclusion • Emissions, waste and natural capital	• Responsible sourcing • Disaster response and resilience • Hunger relief • Plastic waste

Figure 7: Stakeholders & their ESG priorities (Walmart Inc., 2019)

This suggests that collaborations like the one with VeChain may have been instrumental in shifting greater attention toward social sustainability by enhancing traceability, accountability, and visibility into labour conditions across the supply chain. With the help of blockchain technology, Walmart China is able to track each supplier and sub-supplier, which makes labour inspections much easier, as unethical labour practices cannot be hidden or falsified. As stated in the 2021 ESG Annual Summary, in FY Walmart had assessed 14,300 (Walmart Inc., 2021), and in FY2020 approximately 14,000 third-party audits, indicating the ability of the company to identify risks easier internally, without the help of a third party.

Empowerment of Small-Scale Farmers and Suppliers

Walmart's global supply chain strategy has long demonstrated a commitment to empowering small-scale farmers and suppliers, as reflected in multiple annual and ESG reports from as early as 2010 (Walmart Inc., 2010). This long-term engagement signifies that the company recognizes the importance of responsible sourcing. Specifically in recent years, the role of smallholder farmers and local producers has been predominantly reflected in many of Walmart's sustainability initiatives, as seen of Figure 8.

Figure 8: Supporting local, diverse and small businesses (Walmart Inc., 2017)

Blockchain partnerships like the one between Walmart China and VeChain has further strengthened these initiatives. By promoting fair practices and collaboration, blockchain technology helps reduce the power asymmetry between small suppliers and large retailers in the food supply chain (Katsikouli et al., 2021). Critical product data is recorded in a tamper-proof manner, accessible to all stakeholders, and thus, increasing the visibility of small-scale producers, which are more likely to comply with quality, safety, and ethical standards (Suh et al., 2020).

Walmart has recognized such benefits particularly in markets like China with complex supply chains and food safety concerns. As stated in its FY2022 ESG Summary, the Walmart Foundation has awarded more than $67 million in grants since 2017 to support smallholder farmers in Central America, India and Mexico, as well as $25 million to strengthen smallholders in FPOs in India (Walmart Inc., 2022). While direct grants are not reported specifically for China, the focus on technological partnerships offers a systemic empowerment of small producers through digital inclusion that represents a parallel form of support for Walmart’s goals of social sustainability.

4.4. Challenges of Blockchain Technology in GVCs

Despite holding great potential for addressing many current sustainability and transparency issues in GVCs, blockchain technology faces a number of considerable challenges that hinder its widespread adoption and scalability. Mathivathanan et al. (2021) mention some of the barriers to blockchain adoption, such as a general unfamiliarity with newer technologies, and, thus, business owners’ unwillingness to experiment with and commit to new technology, specifically blockchain. Moreover, while data immutability is often seen as a strength, the inability to modify or delete information uploaded on the ledger, especially in the context of evolving data protection regulations along GVCs, may rise data privacy and security concerns. This calls for carefully designed governance frameworks that combine transparency with flexibility and compliance.

4.4.1. Compatibility and interoperability challenges

One of the primary challenges facing blockchain technology is its lack of compatibility and interoperability with existing systems (Kumar & Kumar Singh, 2022), which stems from the decentralized and diverse nature of blockchain networks, each often built with unique consensus mechanisms, data structures, and programming languages. As a result, the integration of blockchain solutions with traditional IT systems can become highly complex and resource-intensive.

VeChain has acknowledged and proactively addressed this issue by designing VeChainThor blockchain to meet all basic requirements for enterprise adoption, including: a proper governance model, a sustainable economic model (the two-token model: VET and VTHO), and a flexible blockchain that complies with changing regulations and could be easily integrated with different technologies such as IoT, RFID, 5G, AI/ML, and big data (VeChain, 2023). Moreover, VeChain has enhanced interoperability by supporting Ethereum Virtual Machine (EVM) compatibility and integrating JSON-RPC, allowing developers and enterprises that are already familiar with Ethereum-based infrastructure to seamlessly port applications and tools from Ethereum to VeChain (VeChain Foundation, n.d.).

4.4.2. Scalability Limitations

Another pressing challenge is scalability. As more participants engage in blockchain networks, the system must handle increased transaction volumes in a fast and efficient way. However, the current scalability of most blockchain networks remains limited, with established platforms such as Bitcoin and Ethereum only capable of processing a relatively small number of transactions per second, typically around 7 and 15, respectively, without compromising speed or incurring high transaction costs (Rao et al., 2024). In global value chains with high-volume environments such as logistics, manufacturing, and retail, delays or cost inefficiencies caused by network congestion undermine the practicality of blockchain-based solutions.

With its PoA consensus mechanism, VeChain's VeChainThor blockchain addresses both scalability and sustainability concerns by producing new blocks approximately every 10 seconds, as previously discussed in the Introduction of VeChain section. A rapid block generation, combined with lower energy consumption and predictable network performance makes VeChainThor very suitable for integration into global value chains. However, trade-offs, such as the increased centralization compared to fully decentralized networks, as discussed in earlier sections of this thesis, must be taken into account.

4.4.3. Privacy Concerns

VeChainThor operates as a public, semi-decentralized blockchain, where, unlike traditional permissioned (private) blockchains, all transactions are publicly verifiable and data, once recorded, cannot be altered or deleted. While this enhances accountability across stakeholders in global value chains, it also raises critical privacy concerns, particularly with the risk of unintended exposure of sensitive business information, proprietary data, or personal identifiers.

While there is some prior literature that acknowledges the theoretical tension between transparency and privacy in blockchain systems, more recent studies have mainly shifted their focus towards other issues (e.g., scalability), and difficulties in the practical applications of digital technologies. Therefore, a notable gap in empirical and applied research is identified on how public or semi-decentralized blockchains, such as VeChainThor, address evolving privacy concerns.

4.4.4. Regulatory Hurdles

Beyond these technical and privacy-related challenges, blockchain adoption in global value chains is also shaped by the legal and institutional context, where strict data sovereignty and regulatory requirements, particularly in China, pose additional hurdles that firms like VeChain must navigate. While BaaS platforms provide control panels, encryption, and network protections (Li et al., 2022), these features may not suffice under Chinese law, where compliance requirements go far beyond technological safeguards. Laws such as the Cybersecurity Law (2017) and Data Security Law (2021) place strict mandates on data localization and tightly control cross-border data flows, especially for core or sensitive data. Layers of oversight are imposed via the Blockchain Information Service Management Regulation (2019), which requires blockchain service providers to register with the Cyberspace Administration of China and to retain user data for extended periods, eroding anonymity and challenging the notion of immutability.

These regulations exacerbate compatibility and interoperability issues, since domestic data sovereignty requirements limit integration with international public blockchains and strain global value chain applications. In this context, VeChain has strategically adapted: shifting focus toward government-aligned use cases (e.g., food safety, sustainability), strengthening ties with local partners, distancing itself from crypto-centric optics, and implementing innovations like fee delegation via ToolChain to enable compliant enterprise use without direct handling of cryptocurrencies.

Table 5: Summary of blockchain adoption challenges and VeChainThor solutions in GVCs

Challenge	Description	VeChain Mitigation	Remaining Gaps
Compatibility & Interoperability	Integration with legacy IT systems is complex due to diverse blockchain architectures	VeChainThor supports EVM, JSON-RPC, IoT/AI/5G integration, flexible governance	Legacy systems may still require significant adaptation; multi-chain interoperability is limited; cross-organization integration remains challenging
Scalability	Limited transaction throughput leads to congestion and higher costs in high-volume environments	PoA, fast block generation (~10 sec), predictable performance, energy-efficient	Increased centralization reduces decentralization benefits; extreme high-volume scenarios may still face delays; scalability trade-offs remain
Privacy Concerns	Public/semi-decentralized ledgers may expose transactions; immutable data risks sensitive information leaks	Transparency for accountability; semi-decentralization for controlled access	No full solution for balancing transparency with privacy; sensitive business or personal data may still be exposed; empirical evidence on privacy solutions is scarce
Regulatory Hurdles	Data sovereignty, compliance laws (e.g., China) restrict cross-border data flow and challenge immutability	Government-aligned use cases, partnerships with local firms, ToolChain fee delegation, distancing from crypto optics	Regulations are complex and evolving; international blockchain integration may remain restricted; legal risks still exist in high-regulation regions

Table 5 summarizes the main challenges of blockchain adoption in global value chains, VeChainThor's mitigation strategies, and the remaining gaps that persist despite these measures.

4.5. Comparative Analysis

This section aims to synthesize insights from the case of VeChain and Walmart China by comparing it against other blockchain-based sustainability initiatives to assess their relative effectiveness, scalability, and impact across global value chains. The comparative evaluation is framed around several dimensions: industry focus, technological innovation, sustainability orientation, geographical coverage, and consumer engagement. The analysis seeks to uncover not only the specific strengths and weaknesses of the VeChain-Walmart partnership but also the broader patterns that emerge when blockchain technology is applied to sustainable supply chains. This includes understanding how different initiatives prioritize certain goals over others, the trade-offs they face in implementation, and the ways in which they interact with existing supply chain structures. Moreover, the evaluation considers the practical implications for stakeholders, including producers, retailers, and consumers, and how these initiatives can influence decision-making and behaviour across multiple levels of the supply chain.

4.5.1. Industry Focus and Range of Use

VeChain's extensive portfolio, which spans a number of industries, including food, fashion, pharmaceuticals, and automotive, makes the company's blockchain solutions seem more flexible than those of some of its competitors. IBM’s Hyperledger Fabric is a modular blockchain framework in collaboration with over 120,000 organizations and 15,000 engineers. Despite its widespread use, it is a permissioned network that requires access and focuses primarily on large-scale logistics and enterprise networks (IBM, n.d.). Its deployments with partners like Maersk and Walmart in the U.S. are adjusted for closed, high-volume ecosystems rather than flexible applications across industries. OriginTrail is another competitor of VeChain that focuses on ensuring data integrity across supply chains, particularly in IoT, transportation, food safety, and construction (OriginTrail, n.d.). Its alignment with global standards such as GS1 enhances interoperability, but its adoption remains more niche and technical compared to VeChain’s commercially oriented ToolChain platform. Previously mentioned companies such as Everledger, Provenance and Waltonchain, on the other hand, offer initiatives suited to particular niches. Even though each of these platforms has advantages of its own, their overall scalability and scope are still limited.

VeChain's partnership with Walmart China is frequently cited as a practical implementation of blockchain for food traceability. However, it also has a relatively limited scale and market penetration, especially when compared to some of IBM's collaboration, e.g., the one with Walmart U.S. through the IBM Food Trust platform. According to Walmart's reports, the latter has achieved bigger influence and is much more frequently highlighted in the company's communications.

4.5.2. Technological Capabilities and Innovations

Other retailers, like Carrefour have also partnered with IBM, using the IBM's Food Trust Platform. In 2018, Carrefour launched the first blockchain initiative in Europe to trace fresh products such as chicken, eggs, milk, and cheese across its supply chain, in France and later in other parts of Europe (Carrefour, 2018). Consumers scan products' QR codes to access information on the product's origin, production methods, and logistics. Similarly, Unilever has partnered with platforms like SAP and Provenance on initiatives such as e.g., GreenToken by SAP to track and verify the origin of its palm oil supply chain. However, both of these initiatives have a smaller level of technological integration - in contrast to VeChain that uses advanced technology to automatically track and update information, they rely more on manual data provided by suppliers. This approach is slower, and offers a higher risk of errors or outdated information.

Technologically, VeChain's edge lies in its Proof of Authority (PoA) consensus mechanism and its strong integration with IoT devices that enable real-time monitoring of environmental and operational metrics. The VeChain ToolChain™'s layered architecture through the BaaS, SaaS, and PaaS components, enhances its adaptability to various industry needs without requiring deep in-house blockchain expertise. This contrasts with IBM's Hyperledger Fabric, which, while enterprise-grade, demands more customization, and other platforms like Everledger and Provenance that lack VeChain's combined use of smart contracts, PoA consensus, and MCT for operational efficiency.

4.5.3. Sustainability Outcomes

From a sustainability perspective, the VeChain-Walmart China initiative produced tangible results. Throughout its reports, Walmart has consistently stated yearly reductions in emissions and waste, as well as ongoing improvements related to their social and supplier responsibility goals. It is important to note that while Walmart China does not disclose specific sustainability goals and company data, by inference, it is reasonable to assume that the initiative contributed to enhanced traceability, reduced food waste, improved logistics coordination, lowered carbon emissions, and supported responsible sourcing within the Chinese division. However, it is also important to recognize that Walmart's global sustainability improvements may be also partially accounted to other initiatives, such as its partnerships with IBM Food Trust, for example.

4.5.4. Geographical Coverage and Regulatory Integration

China is widely recognized as one of the most complex and tightly regulated markets in the world, particularly when it comes to food safety, data governance, and technology deployment. The success of the VeChain-Walmart China initiative in this environment reflects a high degree of adaptability and regulatory compliance. To succeed, a platform has to have the ability to operate within China's strict legal and administrative frameworks, to integrate blockchain technology in a market where digital infrastructure must align with centralized oversight and evolving standards. The involvement of strategic stakeholders such as PwC, Inner Mongolia Kerchin, and CCFA was crucial for ensuring local legitimacy, and compliance.

Most other blockchain initiatives are based in North America and parts of Europe with different regulatory conditions that generally offer more legal clarity on digital innovation, data privacy (e.g., GDPR), and food standards. However, these markets are also characterized by highly decentralized supply chains and a stronger emphasis on consumer data rights, which can create additional complexity for blockchain adoption (Krzyzanowski Guerra & Boys, 2022).

Table 6: Comparative overview of blockchain-based sustainability initiatives in supply chains

Platform	Industry Focus	Sustainability Impact	Scalability / Reach
VeChain (with Walmart China)	Food, fashion, pharmaceuticals, automotive	Improved traceability, reduced waste, enhanced supplier responsibility, potential reductions in emissions	Medium; strong in China but limited global market penetration
IBM Food Trust (e.g., Walmart U.S., Carrefour)	Food & beverage primarily; enterprise logistics	Transparency and traceability, supply chain efficiency, compliance with ESG standards	High; U.S. and EU deployments with large-scale enterprise partners
OriginTrail	IoT, transportation, food safety, construction	Ensures data integrity and interoperability across supply chains	Niche; technical adoption mainly in specialized sectors
Everledger	Diamonds, luxury goods	Transparency in sourcing, anti-counterfeiting, ESG reporting	Limited; industry-specific
Provenance	Fashion, FMCG, small-scale supply chains	Track product origins, verify sustainability claims	Limited; primarily used in small-scale supply chains or niche sectors (sustainable fashion and FMCG)
Waltonchain	Retail, logistics, supply chain management	Supply chain traceability, efficiency improvements	Limited; primarily niche projects

4.5.5. Consumer Engagement and Trust

Walmart has frequently emphasised in its ESG reports that consumer trust is a top priority, especially for food safety, product transparency, and ethical sourcing. This commitment is directly supported by the partnership with VeChain. Since they frequently place more of an emphasis on B2B traceability and less on direct customer interaction, platforms like IBM or Everledger provide less user-level transparency. While this B2B focus enhances operational efficiency and risk management, it generally results in less direct interaction with the end consumer, which limits opportunities for engagement and reducing the visibility of sustainability efforts to the public. Consequently, the VeChain-Walmart model demonstrates a more consumer-centric approach, which goes back to their initial mission stated in their first-ever Whitepaper, as previously discussed in the Introduction of VeChain section of the Analysis.

Table 6 summarizes the above-mentioned initiatives, comparing their industry focus, sustainability impact, scalability, technological capabilities, and consumer engagement to provide a clear overview of how different blockchain platforms perform in supporting sustainable supply chains.

4.6. Implications for Global Value Chains and Sustainability

As demonstrated in the VeChain–Walmart China case, blockchain technology can promote traceability, transparency, and trust, which are all essential for achieving sustainable development goals across interconnected global production networks. This study identifies several best practices that other companies can adopt to improve their sustainability performance and supply chain governance.

Firstly, by including PwC, CCFA, and suppliers like Inner Mongolia Kerchin in their partnership with VeChain, Walmart China ensured technological credibility, regulatory compliance, and broader industry acceptance. Such multi-stakeholder approach illustrates the value of coordinated, cross-sector collaboration in driving innovation and ensuring successful implementation.

Furthermore, end-to-end traceability has been shown in both academic studies and real-world examples to significantly enhance visibility across the supply chain with its real-time tracking. Many companies have already implemented digital technology, not only in the food sector but also in industries such as pharmaceuticals for drug traceability. Industries with such complex product and transaction flows require an effective traceability system (Uddin et al., 2021). Moreover, the combination with IoT sensors that allowed Walmart to monitor environmental conditions such as temperature and humidity during transportation and storage, could also be applied across other sectors dealing with perishable or sensitive goods, such as healthcare, agriculture, or luxury goods.

Another side of the VeChain's case study was the Blockchain-as-a-Service (BaaS) platform used, which allowed Walmart China to customize applications according to specific supply chain needs. This cloud-based service model could serve a wide variety of applications and industries where each company choose what to track, who can access it, and how to use the blockchain.

5. Limitations and Future Research

While this thesis contributes to the growing literature on the intersection between blockchain technology and sustainability in global value chains, several limitations must be acknowledged. These limitations concern both the scope of the study and the methodology adopted, and they highlight areas where future research can provide deeper or more conclusive insights.

5.1. Dependence on Secondary Data

A central limitation of this thesis lies in its exclusive reliance on secondary sources for data collection and analysis. The study draws primarily on academic articles, peer-reviewed journals, industry reports, corporate disclosures, and whitepapers to examine the role of blockchain technology in advancing sustainability within global value chains. These sources provide important and valuable insights into the impact of digital innovations, but also inevitably introduce limitations.

First, the dependence on company-produced publications such as VeChain's Whitepapers and Walmart Inc., as well as Walmart China's global and sustainability reports could potentially introduce a self-reporting bias. Corporate documents are often framed in ways that highlight achievements while downplaying shortcomings, as they are intended not only to inform but also to promote a favourable image to stakeholders. For instance, Walmart's sustainability disclosures frequently emphasize progress toward environmental and social targets, but they may not fully reflect ongoing challenges, partial failures, or negative outcomes. Similarly, as discussed in the Analysis and Discussion section of this thesis, VeChain's claims regarding efficiency, scalability, or environmental advantages of its blockchain infrastructure remain difficult to verify independently. The absence of third-party validation of such claims limits the ability to evaluate their objectivity and accuracy.

Second, reliance on secondary sources precludes the collection of first-hand perspectives from critical stakeholders. Interviews with supply chain managers, regulators, or implementation partners could provide nuanced insights into the organizational and technological challenges of blockchain adoption. Even more importantly, voices from the lower tiers of the supply chain, such as small suppliers, agricultural producers, or factory workers, remain absent. Their experiences are essential to fully assess whether blockchain initiatives genuinely improve transparency, social equity, and working conditions, or whether they primarily serve the interests of multinational corporations. Without these perspectives, the findings risk being skewed toward the official narratives of powerful actors.

Third, secondary data often suffers from time lags and selectivity. Some corporate reports and whitepapers analysed in this study are published annually or bi-annually and thus may not capture the most recent developments or setbacks in blockchain implementation. VeChain's most recent whitepaper, for instance, is already two years old, which suggests that parts of this analysis may reflect an outdated snapshot of the VeChain-Walmart China initiative rather than its current, real-time impact. Compounding this issue is the fact that media coverage of Walmart China's use of VeChain has largely ceased, with little independent reporting on how the collaboration is functioning today. Furthermore, the available data tends to emphasize measurable outcomes that corporations are willing to disclose, while less tangible but equally important aspects, such as internal resistance to technological change, hidden costs of implementation, or informal labour practices, remain largely invisible.

Although efforts were made to triangulate data with independent reports, the lack of primary data collection such as interviews, direct observations, or surveys, restricts the depth of the analysis and may not fully capture the perspectives of all actors involved, especially suppliers and workers at the lower tiers of the value chain. Subsequent research should prioritize the collection of primary data through interviews, surveys, or ethnographic fieldwork, which would allow researchers to include perspectives from suppliers, workers, and other underrepresented stakeholders. This would create a more balanced and holistic picture of blockchain's effects across the different tiers of global value chains. Furthermore, longitudinal studies could be beneficial for future research, as well as the analysis of comparative case studies across industries and regions, since blockchain adoption may differ between food supply chains, luxury goods, pharmaceuticals, or manufacturing.

5.2. Limited Access to Quantitative Evidence

Another important limitation of this thesis lies in the absence of detailed quantitative data, particularly with regard to Walmart China's internal sustainability metrics. The analysis benefits from a broad range of secondary sources, including global Walmart reports, academic studies, and industry benchmarks, but it does not have direct access to granular, China-specific performance indicators. Data on measurable outcomes such as waste reduction, carbon emissions, or labour conditions within Walmart China's supply chains is either not publicly disclosed or only presented in highly aggregated form at the global level. As a result, the assessment of blockchain's sustainability impact in the context of the VeChain-Walmart China collaboration remains approximate. This approach provides a reasonable proxy, but it limits the precision with which the actual environmental, social, and economic outcomes of blockchain implementation can be evaluated. In particular, it remains difficult to determine whether the positive sustainability effects frequently highlighted in corporate reports, such as reductions in food waste or improvements in traceability, are directly attributable to the use of VeChain's blockchain solution or to other parallel initiatives. The reliance on indirect indicators also has implications for the validity of the findings, which weakens the opportunity to make strong causal claims about blockchain's contribution to sustainability.

To address these shortcomings, future research should aim to integrate quantitative methods alongside qualitative analysis. Supplier audit scores, food waste statistics, carbon footprint records, or energy efficiency measures specific to Walmart China could allow for a far more rigorous evaluation of blockchain's impact in the collaboration. Moreover, combining these metrics with independent third-party audits could reduce the risk of bias inherent in self-reported corporate disclosures. This point is particularly relevant to RQ1, which asks how blockchain contributes to greater transparency in global value chains. Without independent verification, it is difficult to establish whether blockchain-enabled transparency is genuine or simply a new form of corporate signalling. In line with the first limitation discussed in this chapter, longitudinal data collection and cross-case comparisons could also be particularly valuable, as they would allow researchers to track changes in key sustainability indicators over time and identify whether the effects observed in the Walmart China–VeChain collaboration are unique to the food retail sector or can be replicated in other contexts.

5.3. Case Study Generalizability

This study is based on a single, in-depth case, focusing on a partnership that provides rich, detailed insights directly relevant to the research questions. The findings offer valuable understanding but cannot be generalized to all industries, regions, or blockchain initiatives. Global value chains differ considerably in terms of structure, complexity, regulatory environment, and technological maturity. Strategies that prove effective in the food supply chain in China, for example, may not be directly transferable to sectors such as luxury goods, pharmaceuticals, or manufacturing in other regions, where operational challenges, consumer expectations, and regulatory requirements differ. Moreover, VeChain's technological and organizational model is unique, with its hybrid public-private blockchain approach and the ToolChain platform, and may not reflect the strategies or capabilities of other blockchain providers. As a result, the study offers insights that are illustrative rather than universally representative.

Consequently, the study should be understood as offering illustrative insights rather than universally applicable conclusions. It highlights how blockchain can enhance transparency, efficiency, and trust in a particular supply chain context, but further research involving multiple cases across diverse sectors and geographies would be necessary to draw broader generalizations about the role and effectiveness of blockchain in global value chains.

6. Conclusion

The purpose of this thesis has been to explore the role of blockchain technology and smart contracts in addressing sustainability challenges in global value chains, with a particular focus on transparency, traceability, social equity, and resource efficiency. Guided by three research questions, the study examined how blockchain can improve the efficiency and sustainability of supply chains in multinational enterprises, how blockchain-enabled traceability can contribute to better labour conditions and social equity, and how smart contracts can facilitate resource allocation and reduce certification costs. To address these questions, the thesis applied a qualitative case study design, centering on the collaboration between VeChain and Walmart China as a pioneering example of blockchain adoption in global food supply chains.

The findings of this study underscore that blockchain is far more than a financial innovation originally tied to cryptocurrencies; it is a foundational digital infrastructure with the capacity to reshape economic, social, and environmental systems. The analysis of the VeChain-Walmart China initiative demonstrates that blockchain can meaningfully enhance supply chain transparency, improve food safety, and empower consumers through access to verifiable product information. At the same time, blockchain holds transformative potential for advancing corporate sustainability goals, enabling a shift from reactive, compliance-driven approaches to proactive and data-driven governance of global operations.

6.1. Theoretical Implications

From a theoretical perspective, this thesis contributes to the growing body of literature on the intersection of digital technologies and sustainability. Existing research has often focused on the technical mechanics of blockchain or its efficiency benefits in logistics and finance. By contrast, this study places sustainability at the centre of the discussion, showing how blockchain can address systemic issues such as modern slavery, environmental degradation, and inefficient certification practices. The case study of VeChain and Walmart China illustrates how blockchain can serve as a bridge between Industry 4.0 technologies, institutional frameworks, and sustainability imperatives. This demonstrates the importance of not only technical but also organizational and regulatory factors in shaping blockchain adoption.

One of the most important insights from this research is that blockchain enhances trust in environments where complexity and fragmentation have historically undermined accountability. In global value chains, which span multiple countries, jurisdictions, and tiers of suppliers, traditional monitoring systems are often inadequate to ensure compliance with labour standards, environmental regulations, or product safety requirements. Blockchain's immutable and decentralized ledger provides a mechanism for real-time verification and tamper-proof record keeping. In the VeChain-Walmart China case, this feature translated into tangible outcomes: improved traceability of food products, reduced risk of fraud, and higher consumer confidence. These findings suggest that blockchain can play a decisive role in strengthening resilience and legitimacy in GVCs, particularly in industries with high sustainability risks.

Equally significant is the potential of blockchain to advance social equity through more direct and transparent labour compensation. Smart contracts can automate wage payments, reduce the risk of wage theft, and limit the power of exploitative intermediaries. While this potential was not fully realized in the Walmart China case, the broader literature and analysis suggest that the deployment of blockchain-based systems could contribute to reducing modern slavery and ensuring fairer labour practices. In this respect, blockchain should be seen as part of a larger ecosystem of governance tools that combine digital technology with institutional oversight.

Moreover, blockchain offers promising applications for environmental sustainability. Its ability to support circular economy models, monitor carbon emissions, and verify the provenance of recycled materials could help firms transition from linear production systems to regenerative, closed-loop models. Smart contracts could further incentivize environmentally responsible practices by automatically enforcing compliance with carbon taxation or recycling policies. The case study showed that Walmart China, through blockchain integration, could better monitor supply chains for food safety and waste reduction. While these achievements primarily addressed food security, they also reflect broader environmental benefits by reducing spoilage and optimizing resource use.

However, the study also reveals important limitations and challenges. Blockchain is not a cure-all for sustainability problems, and its successful implementation requires organizational readiness, supportive regulatory environments, and effective stakeholder collaboration. The energy consumption of certain blockchain systems, particularly those based on Proof of Work, raises concerns about the technology's environmental footprint. Although VeChain's Proof of Authority mechanism claims to be more energy efficient, the partial centralization inherent in this model raises questions about governance and inclusivity. Moreover, the "garbage in, garbage out" dilemma persists: if inaccurate or manipulated data is entered into the blockchain, the immutability of the ledger only preserves false information. This highlights the need for robust verification mechanisms and third-party audits, which, while potentially costly, remain essential to ensuring the integrity of blockchain-based sustainability solutions.

Despite these challenges, the overall implications of this study are optimistic. Blockchain technology has the potential to act as an enabling infrastructure for the Sustainable Development Goals. Through the promotion of responsible consumption and production (SDG 12), supporting decent work and economic growth (SDG 8), and enhancing industry innovation and infrastructure (SDG 9), blockchain could help realign global production systems with long-term sustainability objectives. The Walmart China case provides a blueprint for how this potential can be realized, showing that blockchain can be integrated into existing supply chain practices while delivering measurable benefits for transparency, accountability, and consumer trust.

6.2. Practical Implications

For practitioners, the study highlights the importance of aligning blockchain adoption with broader sustainability strategies. Companies should view blockchain not as a stand-alone technology but as part of an integrated ecosystem that includes IoT, AI, and regulatory frameworks. Building consumer trust, engaging suppliers, and investing in organizational capabilities are as important as the technical deployment of blockchain. For policymakers, the findings suggest that regulations should encourage innovation while setting clear standards for data integrity, privacy, and sustainability reporting. International coordination will be especially critical, given the cross-border nature of GVCs and the global scope of sustainability challenges.

Ultimately, this thesis argues that blockchain technology represents both a technical innovation and a social contract. It is not only a ledger of transactions but also a ledger of trust, responsibility, and accountability. As businesses, governments, and consumers continue to grapple with the urgency of climate change, labour exploitation, and resource depletion, blockchain provides a tool that can support systemic change. However, its promise will only be fulfilled if stakeholders are willing to invest in its responsible implementation, address its limitations, and embrace its potential as a catalyst for sustainable development.

6.3. Final Remarks

In conclusion, blockchain technology and smart contracts have the capacity to transform global value chains by making them more transparent, equitable, and sustainable. The VeChain-Walmart China case exemplifies both the opportunities and the challenges of this transformation. While blockchain is not a silver bullet, it offers a powerful foundation for rethinking how goods are produced, traded, and consumed in an interconnected world. As Industry 4.0 continues to unfold, blockchain's role in shaping the future of sustainable business practices will likely expand, providing not only new efficiencies but also new forms of accountability and collaboration across global value chains. This thesis contributes to this emerging discourse by demonstrating that the future of sustainability may well depend on how effectively we harness the disruptive power of blockchain to align economic progress with social and environmental responsibility.

VII. References

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