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"Optimizing payment procedures in the supply chain of Ethiopian coffe: A Blockchain based approach to enable ESG compliance for all stakeholders."

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1. Introduction

1.1 Research Background

Globalization has transformed the economic landscape of the modern world, offering exemplary opportunities for integration, innovation, and growth. Yet not all regions benefit equally from this process. Africa is often cited as an example of the negative effects of globalization. While globalization has fostered economic growth in many regions worldwide, Africa has struggled to integrate into the global economy successfully. Over the past few decades, Africa´s share in global trade has consistently declined, with emerging economies in Asia and Latin America overtaking its position. Several factors contribute to this economic downturn, including weak infrastructure, political instability, and an overreliance on raw material exports rather than diversified economic growth. Historically, Africa´s role in the global economy has been shaped by external forces. The continent was drawn into global trade networks during colonization, serving primarily as a source of raw materials for industrialized nations. Rather than establishing local production or technological advancement, this model rooted a pattern of extraction and dependency. In the last decades, many African countries have remained locked into this role, exporting unprocessed commodities while importing finished goods. This imbalance has prevented the continent from climbing the global value chain and building the internal capacity needed for sustainable growth.

Today, African economies are still heavily reliant on a narrow set of exports such as coffee, cocoa, crude oil, and minerals making them vulnerable to price volatility and global market shocks. At the same time, imported goods, often subsidized or second-hand, dominate domestic markets, stifling the development of local industries. This structural dependency results in capital outflows, limited job creation, and a persistent lack of innovation. The absence of industrial policy and investment in strategic sectors means that Africa remains peripheral in global production systems, a position some analysts now equate with “modern economic servitude” or “neo-colonialism.” The term reflects a situation where wealth flows out of the continent while economic sovereignty remains elusive for most African nations.[1]

In contrast, several Asian countries have successfully transitioned from agricultural to industrial economies by identifying and investing in key sectors such as electronics, textiles, automotive production, and technology. Through coordinated government

[1] Internet Encyclopedia of Philosophy (Neocolonialism)

policy, investment in education and infrastructure, and targeted foreign partnerships, countries like China, South Korea, and Vietnam have built globally competitive industries and integrated themselves into complex supply chains. Their success illustrates that globalization can be fastened for development if guided by strategic vision and institutional capacity. Unlike Asian economies that have successfully leveraged globalization for industrialization and trade expansion, Africa remains largely a supplier of unprocessed resources, which limits its ability to compete on a global scale.[2]

Africa´s experience has been markedly different. The continent´s integration into global trade has largely been driven by the interests of multinational corporations and elite political networks. These actors often prioritize short-term profits from extractive industries over long-term investments in innovation, education, or infrastructure. The result is a continent that remains rich in resources but poor in developmental outcomes. This paradox is deepened by widespread corruption, weak governance, and a lack of transparent institutions. Capital flight is common, with profits often reinvested abroad rather than into local economies, further entrenching inequality and underdevelopment. The rural and agricultural sectors, which are employing the majority of Africa´s population, are especially affected by this imbalance. Coffee farming, for example, generates significant global revenue, yet smallholder farmers in East and West Africa often live on less than $2 USD a day. They are caught in long, opaque supply chains where intermediaries extract much of the value, and farmers lack access to real-time pricing, financing, or reliable buyers. Despite the growing demand for ethically sourced and sustainably produced goods, African producers rarely capture a fair share of the final consumer price. These dynamics raise questions about fairness, justice, and inclusion in the global economy. For many Africans, the promise of globalization has not translated into material improvements in living standards. Instead, the continent remains dependent on external actors for investment, technology, and market access. This dependency combined with exploitative labor practices, low wages, and limited social mobility leads some to view current global trade structures as a continuation of colonial patterns under new guises. Nevertheless, there are signs of progress. Across the continent, initiatives to diversify economies and reduce reliance on commodity exports are gaining traction. In sectors like digital services, agribusiness, and renewable energy, new opportunities are emerging. Moreover, in recent years, Africa has witnessed a remarkable surge in entrepreneurial

[2] Bundeszentrale für politische Bildung (Globalisierung - Fakten)

activity. Cities such as Lagos, Nairobi, and Cape Town have emerged as vibrant tech hubs, fostering startups that span various sectors, including agriculture, healthcare, and, most prominently, fintech. Fintech innovations are pivotal in addressing financial inclusion challenges in Africa.[3]

The African fintech sector is experiencing remarkable growth and transformation, despite facing macroeconomic headwinds such as rising living costs, currency devaluations, and slowing Gross Domestic Product growth. According to McKinsey´s report *"Redefining Success: A New Playbook for African Fintech Leaders"*, Africa´s fintech revenues could grow from approximately $10 billion USD in 2023 up to between $25 billion USD and $47 billion USD by 2028. This forecast assumes that fintech penetration could rise from the current 5-6% to around 15%. The projected expansion is driven by multiple structural advantages: Africa´s rapidly growing and predominantly young population, with over 60% of its population under the age of 25, increased internet and smartphone penetration, and the widespread use of mobile money platforms.[4] By leveraging mobile technology and digital platforms, fintech startups provide services such as mobile banking, microloans, and insurance to populations previously excluded from the formal financial system. This inclusion strengths economic empowerment, enabling individuals and small businesses to participate more actively in the economy. Collaborative efforts between governments, private sector players, and international partners are essential to create an enabling environment for fintech to thrive. In relation to fintech, mobile money is rapidly expanding across Africa, with services like M-Pesa playing a key role in enhancing financial inclusion by offering accessible digital financial services through mobile networks.

This thesis builds on all these insights by exploring how blockchain technology, combined with fair trade frameworks and regulatory shifts like the German Supply Chain Due Diligence Act, could serve as catalysts for inclusive economic growth in Africa. By analyzing the potential of decentralized technologies to enhance transparency, payment efficiency, and traceability, the research seeks to offer practical models that enable African producers particularly in the coffee sector of Ethiopia to engage with global markets on fairer terms.

[3] McKinsey & Company (African fintech leaders)
[4] McKinsey & Company (African fintech leaders)

1.2 Problem Statement

Despite significant global demand for ethically sourced and sustainably produced goods, smallholder coffee producers in African regions continue to face systemic inequalities in international trade, characterized by delayed payments, insufficient market transparency, and substantial economic vulnerability. Particularly in countries like Ethiopia, traditional payment infrastructures involving multiple intermediaries have proven inefficient and financially disadvantageous to farmers. Concurrently, European coffee wholesalers face increased regulatory pressure from frameworks, requiring verifiable compliance and transparent supply chains. However, current compliance solutions often fail to address the core financial inclusion issues faced by smallholder farmers. This gap underscores the critical need for innovative digital payment systems capable of integrating transparency, economic empowerment, and regulatory compliance into a unified model, positioning blockchain technology as a promising avenue for transformational change. These challenges are amplified by the limitations of traditional trade infrastructure, which still relies heavily on fragmented, paper-based systems. Problems such as fragmented data storage, untransparent product journeys, compromised data integrity, and visibility deficits across the supply chain hinder transparency and efficiency. Regulatory obstacles at borders further delay processes and increase the administrative burden, especially in agricultural trade involving multiple international actors. In this context, digitizing trade documentation emerges as a necessary step forward. Furthermore, digital trade systems can help close the trade finance gap, increase small and medium-sized enterprise productivity, and reduce operational risks related to fraud or document loss. This transformation holds great potential for emerging markets, particularly for smallholder farmers and exporters in the Global South, who are currently excluded from many global value chains due to a lack of digital infrastructure and verifiable documentation.

This thesis is therefore anchored in the belief that digitization must serve not only compliance or efficiency objectives but also the broader development of smallholder producers in coffee-exporting countries such as Ethiopia. In alignment with the United Nations Sustainable Development Goals, the focus lies especially on Goal 1: “No Poverty”, Goal 8: “Decent Work and Economic Growth”, and Goal 10: “Reduced Inequalities”, which together emphasize the importance of inclusive economic participation, fair compensation, and equitable access to global markets.[5] By improving the speed, transparency, and reliability of payments, digital infrastructures

[5] UN Department and Department of Economic and Social Affairs (SDG Goals)

such as blockchain-based systems can directly contribute to the economic empowerment of marginalized farming communities and support the creation of fairer and more sustainable agricultural supply chains.

Blockchain technology in combination with mobile payment systems offers a promising way to address these issues by enabling automated, traceable, and cost-effective payment systems. Yet, there is a lack of applied research and implementation strategies that examine how such technologies can be practically connected and adopted in the context of African coffee production, and what role European stakeholders must play in this transformation. This thesis addresses those pain points by investigating the feasibility, challenges, and responsibilities involved in implementing a blockchain-based payment system that promotes both economic fairness for producers and compliance for international buyers.

1.3 Research Objectives and Questions

The primary objective of this thesis is to investigate how blockchain technology in combination with mobile payment systems can be used to improve transparency, efficiency, and fairness in the payment processes of the African coffee industry. The research aims to explore the potential of blockchain-based systems to ensure timely, secure, and traceable financial transactions between coffee producers and international buyers, with a focus on promoting financial inclusion and meeting legal and ethical standards across the supply chain.

To reach these goals, the thesis first seeks to compare different blockchain platforms to determine which is most suitable for handling cross-border payments in an agricultural context. This includes analyzing technical features of blockchain technology, smart contract capabilities, consensus mechanisms, scalability, and integration with mobile payment systems. A comparative analysis in advance aims to justify which blockchain emerges as the most viable option for real-world deployment in coffee-producing regions.

An additional central component of the upcoming analysis is to highlight the untapped potential within the Fair-Trade coffee sector, particularly in Germany and across Europe. As consumer awareness continues to grow around ethical sourcing, transparency, and sustainability, Fair-Trade-certified products, especially coffee, are gaining momentum as a preferred choice in the retail and hospitality markets. A statistical data overview aims to quantify the economic opportunity that arises from aligning with these values, revealing how both demand and purchasing behavior are shifting in favor of traceable and socially responsible supply chains. At the same time,

increasing risk of greenwashing, where companies falsely claim ethical or sustainable practices to capitalize on this trend without delivering measurable impact, will be critically analyzed. By applying blockchain-backed traceability and stablecoin-based payment models, this thesis shows how real transparency can replace vague marketing claims, turning Fair-Trade from a label into a verifiable standard of impact. The analysis not only demonstrates the economic upside of engaging with the Fair-Trade movement but also reinforces why technological integration is essential for protecting consumer trust and ensuring genuine producer benefits in the European consumer market. It examines how blockchain technology can enhance trust, data validation, and legal traceability throughout the whole supply chain. This includes evaluating how environmental and quality-related data collected at the production level can be securely stored and shared via blockchain, and how these technologies can be aligned with due diligence requirements imposed by German and European law.

Furthermore, the economic dimension of blockchain implementation by identifying the potential benefits and challenges that such a system poses for small-scale coffee farmers is addressed. This involves a detailed cost-benefit case study, assessing how direct blockchain-based payments might reduce transactions costs or dependency on intermediaries, improve liquidity, and create long-term income security for Ethiopian coffee farmers. At the same time, technological barriers, such as limited digital infrastructure, and emission concerns that might hinder adoption are considered.

Therefore, the role and responsibility of European coffee wholesalers in the implementation of blockchain systems is addressed. The thesis explores how these actors can be held accountable for promoting the use of transparent and equitable payment technologies, not only to fulfill their legal obligations but also to contribute to a more sustainable and ethical coffee supply chain. Closely related to this is the question of which specific steps, whether technical, organizational or financial, are necessary to ensure that wholesalers do not merely comply with regulations but actively support coffee farmers in the adoption and long-term use of blockchain solutions.

To concretely address these challenges, this thesis will specifically test the hypothesis that blockchain-based stablecoin payments represent the simplest and most economically viable solution for Ethiopian coffee farmers, particularly when compared to traditional mobile money integrations such as M-Pesa. The analysis explicitly seeks to validate whether a tokenization-based infrastructure can effectively mitigate the impacts of local inflation, streamline transaction processes, and enhance compliance transparency for European importers. Furthermore, the research aims to

quantify the direct socioeconomic impact of adopting blockchain technology, assessing its potential to elevate farmers´ income above the World Bank´s defined extreme poverty threshold of $2.15 USD per day.[6] Ultimately, this thesis intends to demonstrate not only the technical feasibility but also the significant economic and social advantages of blockchain adoption in agricultural value chains, thereby offering actionable insights for stakeholders across both Ethiopian and European markets.

1.4 Scope and Limitations

This thesis focuses on exploring the implementation of blockchain-based payment systems in the coffee industry, with a particular emphasis on the integration of blockchain technology and mobile money services to support smallholder coffee producers in Ethiopia. The research is framed within the context of increasing global demands for ethical supply chains and the legal obligations arising from regulatory frameworks such as the German Supply Chain Due Diligence Act. The study aims to identify practical ways in which blockchain technology can facilitate efficient, transparent, and fair payments to Ethiopian coffee farmers, while simultaneously addressing the responsibility of European coffee wholesalers in promoting financial inclusion and technological adoption on the ground.

The scope of the thesis includes a comparative analysis of blockchain infrastructures, focusing on Ethereum, VeChain, and Solana, due to its various fields of use and existing features. The study also incorporates the role of data integration and digital trade platforms in verifying quality, sustainability, and traceability in supply chain transactions via blockchain technology. However, this aspect remains secondary to the primary goal of establishing a payment framework. The research primarily centers on the socioeconomic benefits and technological feasibility of such a solution for coffee producers in Ethiopia boosting their revenue share above the poverty threshold level. A cost-benefit case study is employed to illustrate the real-world application of the model from a financial perspective, followed by a deeper look into technology, meaning tokenization mechanisms and smart contract execution.

Nevertheless, there are several limitations to the research. Firstly, the thesis does not include direct empirical fieldwork in Ethiopian farming communities. Numbers and assumptions made are based on research and mostly broken down to an average, knowing each farmer must be reviewed under certain conditions. A detailed analysis of climate change factors and the effect on productivity for Ethiopian coffee farmers

[6] World Bank (Fact Sheet, Global Poverty Lines)

is also out of scope. Instead, this thesis relies on existing case studies, news articles, industry reports, blockchain whitepapers, and statistics to simulate a practical implementation scenario. Secondly, the study focuses on one blockchain as the most promising solution and does not include in-depth technical benchmarking of alternative blockchain infrastructures beyond the initial comparative assessment. Given the rapid pace of innovation in the blockchain space, continuous analysis of both existing and emerging technologies is essential to ensure long-term relevance, scalability, and regulatory alignment of proposed solutions. Thirdly, while the thesis addresses regulatory issues and the role of European wholesalers in promoting fair trade and compliance, it does not provide an exhaustive legal analysis of international trade law or national tax systems in connection with considerably newer technology like blockchain due to the lack of regulations. Another point of critique is the little explored field of practical implementation of blockchain technology used in agriculture industry and the lack of validated data, with only a few existing examples accessible. Detailed case studies and their outcome must be evaluated carefully in this thesis due to the short period the technology is used in the agriculture industry and their international supply chains. Lastly, the creation of the "Coffee Token" is only described in theory and not realized in practice, due to the general scope and length of the thesis which focuses more on the economic part rather than programming itself. Existing use cases and their token structure are added in the appendix as references.
Finally, the study is limited to the coffee sector as a representative case of agricultural supply chains in Sub-Saharan Africa. While the findings may be transferable to other agricultural products or regions, such generalizations must be made with caution. The thesis also assumes a minimum level of digital infrastructure and mobile money penetration, which may vary across countries and regions. Despite these limitations, the research provides valuable insights into the intersection of blockchain technology, financial inclusion, and ethical supply chain management, contributing to a growing body of work on the digital transformation of global agriculture.

1.5 Methodology and Structure of the Thesis

This thesis adopts a multi-method approach to examine the feasibility and economic impact of blockchain-based payment systems, specifically focusing on Solana´s integration with M-Pesa in the Ethiopian coffee sector, with a particular focus on the role of European coffee wholesalers in supporting implementation efforts. Given the complexity of the topic, a combination of qualitative and quantitative research methods ensures comprehensive analysis. The research aims to provide an in-depth assessment

of blockchain technology´s potential in facilitating secure, efficient, and transparent transactions while addressing regulatory challenges, stakeholder responsibilities, coffee and Fair-Trade market growth and practical implementation strategies in the context of the Supply Chain Due Diligence Act. The methodology includes a theoretical literature review, a comparative blockchain analysis, and a cost-benefit case study with following technical implementation proposal supported by a Balanced Scorecard, each contributing to a holistic understanding of the subject.

Platforms like Bitpanda and Coinbase formed the foundational basis for this research, offering accessible insights into core blockchain concepts while also reflecting current trends in adoption, technology, and regulatory evolution across the cryptocurrency sector. The research continues with an extensive literature review to establish a theoretical foundation on blockchain technology, supply chain payments, and mobile money systems. This includes an analysis of crypto magazine articles, annual reports, and industry reports from organizations such as the Global Blockchain Business Council or the German Society for International Cooperation (GIZ). Whitepapers from several blockchains itself serve as additional input. Another research field, backed up by statistics, is the growing demand of Fair-trade products in the German and European market in connection with the projected growth of the coffee market in general.

A key methodological component of this research is the comparative analysis of blockchain solutions, specifically evaluating Ethereum, VeChain and Solana, assessing their suitability for supply chain finance based on technical capabilities, scalability, cost-efficiency, and the ability to integrate with mobile money systems. The comparative study highlights both the advantages and limitations of each blockchain in facilitating efficient, transparent, and decentralized financial transactions. This evaluation leads to the identification of Solana as the most appropriate blockchain for the proposed payment system, based on its superior transaction speed, low costs, energy efficiency and smart contract utility, particularly for smallholder coffee farmers.

A crucial part of this thesis is the cost-benefit case study based on the gathered data and the projected market growth. It introduces a hypothetical financial and technical implementation model for Solana-based payments integrated with M-Pesa. The case study outlines a model in which smallholder coffee farmers in Ethiopia receive direct, automated payments using smart contracts triggered by delivery confirmations and quality verification. It evaluates the design of such a payment flow, the technical implementation using Solana smart contracts, and the additional mechanisms for fiat withdrawal through M-Pesa and off-ramp services. Furthermore, it explores potential

risks such as fraud prevention, compliance with financial regulations, and the economic viability for farmers and the operational responsibility of European coffee wholesalers.

This thesis relies on a combination of primary and secondary data to ensure a comprehensive and multi-dimensional understanding of the research subject. Secondary data sources have been instrumental in analyzing macroeconomic and industry-specific trends, particularly regarding the coffee export markets of Ethiopia and Africa as a whole. These include trade statistics, international development reports, offering insight into export volumes, value chains, and production dynamics. Additionally, market research studies and consumer reports were used to assess the growing demand for Fair Trade-certified products in Germany and Europe, including consumption behavior, willingness to pay premiums, and projected growth rates for ethically sourced coffee. To support the technological aspect of the thesis, in-depth secondary data was collected from blockchain infrastructure providers. Furthermore, existing literature and previous case studies examining blockchain implementation in supply chains, especially in agriculture and Fair-Trade contexts provided valuable frameworks for evaluating feasibility, efficiency, and scalability of such solutions. Where necessary, these insights were triangulated with primary data, including technical documentation from blockchain developers and stakeholder insights from industry actors.

The thesis is structured into seven interconnected chapters, each contributing to a broad understanding of the topic described. It begins with an introduction that outlines the background of research, problem statement, objectives, and the methodology described in this chapter. The second chapter introduces the mobile payment system M-Pesa, which is already used across African countries to perform financial transactions. Due to the following cost-benefit analysis, a short sub-chapter about the Society for Worldwide Interbank Financial Telecommunication (Swift) and Visa Inc. is implemented afterwards. The third chapter establishes the theoretical foundation by covering blockchain fundamentals, smart contracts and decentralized applications (Dapps). The fourth chapter presents a comparative analysis of three blockchain platforms, leading to a technology selection tailored to the specific requirements of the use case. The fifth chapter explores the legal and compliance context, including a focused analysis of the responsibilities of European wholesalers under the Supply Chain Due Diligence Act. A detailed market analysis of the Fair-Trade market in Germany and Europe due to scalability reasons follows. The sixth chapter starts with an in-depth analysis of the African and Ethiopian coffee market specifically. It

afterwards delivers the core case study of this research, which is the cost-benefit case study and demonstrates how Solana can be implemented for payments in the coffee sector from a financial and technical perspective. In the seventh chapter, the thesis identifies and discusses key barriers to blockchain adoption, including legal, infrastructural, structural, educational, environmental, and financial challenges, while proposing targeted mitigation strategies to effectively address these obstacles. Finally, the last chapter concludes with a summary of the findings and suggestions for future research directions and upcoming challenges.

By systematically evaluating blockchain-based payment systems from economic, technological, regulatory, and ethical perspectives, this thesis provides actionable insights and practical recommendations aimed explicitly at improving financial inclusion, economic stability, and sustainability within Ethiopian coffee farming communities. The structured approach ensures logical progression, beginning from theoretical exploration, comparative blockchain analysis and market data to a detailed economic case study and technical implementation framework. Central findings explicitly highlight the advantages of blockchain-enabled stablecoin payments, underscoring their superiority in simplicity, cost-effectiveness, and inflation resistance compared to traditional mobile money integrations like M-Pesa. Thus, the research clearly identifies blockchain tokenization as the preferred strategic solution for fostering equitable, sustainable, and compliant international coffee trade.

2. The Role of Mobile Money in Africa – The Case of M-Pesa

2.1 Evolution and Adoption of Mobile Money Services

Over the past two decades, mobile money has fundamentally reshaped the financial landscape in Africa, providing millions with access to essential financial services and reducing reliance on traditional banking infrastructure. Mobile money services have played a crucial role in financial inclusion, allowing individuals, particularly those in rural and underserved communities, to perform transactions, save money, and access credit without the need for a formal bank account. The significance of mobile money is particularly evident in Sub-Saharan Africa, which continues to be the global leader in mobile financial services. M-Pesa, launched in 2007 by Safaricom in Kenya, has become one of the most successful mobile money platforms globally, profoundly transforming financial transactions and local economies. Initially designed as a simple money transfer service, M-Pesa has evolved into a comprehensive financial ecosystem, offering services such as savings, loans, and merchant payments.

The GSMA´s "*State of the Industry Report on Mobile Money 2024"* provides a comprehensive overview of the mobile money sector´s evolution, highlighting its pivotal role in advancing financial inclusion, particularly in developing economies. As of 2023, there are 1.75 billion registered mobile money accounts globally, processing a volume of 29 billion remittances with transactions worth $1.4 trillion USD annually. The year-on-year growth rate shows an increase of 12% of registered mobile money accounts, 14% of transaction value and 33% of processed remittances in 2023.[7]

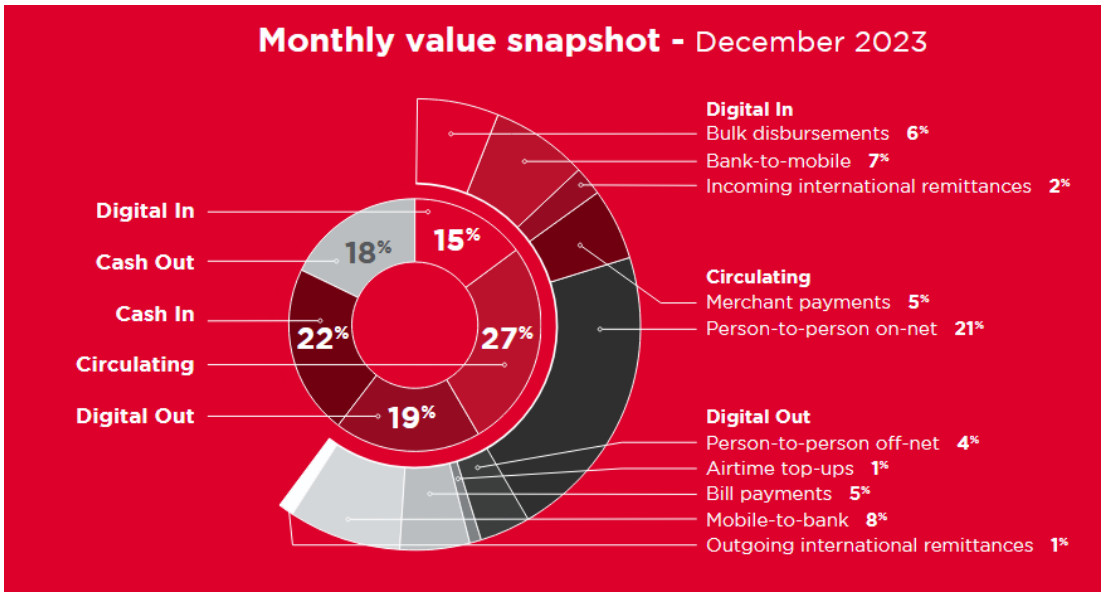

Image 1: GSMA (Industry Report on Mobile Money 2024), p. 10

As shown in the snapshot above, the distribution of mobile money transaction value in December 2023 is split across five main categories: 27% Circulating, 22% Cash In, 19% Digital Out, 18% Cash Out, and 15% Digital In.

Within the dominant "Circulating" category, Person-to-Person (on-net) transfers represent the most significant subcomponent, reflecting the core role of mobile money as a peer-to-peer exchange infrastructure with 21%. Meanwhile, international transactions remain marginal with only 1% outgoing and 2% incoming international remittances. This disparity illustrates the continued difficulty of cross-border transactions in mobile ecosystems, due to both regulatory fragmentation and a lack of technical interoperability between mobile money operators in different countries.[8]

Furthermore, as of 2023, Sub-Saharan Africa accounts for 48% of all registered mobile money accounts worldwide, with 835 million registered users actively using these services. This marks an increase of 133 million new accounts in just one year,

[7] GSMA (Industry Report on Mobile Money 2024), p. 9
[8] GSMA (Industry Report on Mobile Money 2024), p. 10

underscoring the rapid adoption and integration of mobile money into everyday life. The region dominates mobile financial services, processing transactions worth $912 billion USD annually, equivalent to $2.5 billion USD per day. Notably, Sub-Saharan Africa accounts for two-thirds of global transaction values, emphasizing its dominant position in the mobile money industry.[9]

One of the most significant drivers of mobile money adoption in Africa is the vast agent network, which enables financial transactions even in areas with limited internet or banking infrastructure. By 2023, Sub-Saharan Africa had over 10 million registered mobile money agents, with 49% actively processing transactions each month. These agents serve as intermediaries, enabling users to deposit and withdraw cash, send remittances, and pay for goods and services. While West Africa leads in terms of the sheer number of agents, East Africa has the highest proportion of active agents, demonstrating regional variations in service penetration. In comparison, regions such as South Asia and Latin America have significantly lower agent activity rates, highlighting the unique reliance on mobile money agents in African markets.[10]

Beyond simple money transfers, mobile money platforms have evolved to support a wide range of financial services, including merchant payments, international remittances, loan disbursements, and bill settlements. Merchant payments have seen substantial growth, contributing significantly to digital transaction values. In countries like Ghana, Kenya, and Nigeria, businesses of all sizes now rely on mobile money as a secure and efficient means of conducting transactions. The introduction of Quick Response (QR) code-based payments and Near Filed Communication (NFC)-enabled transactions has further enhanced convenience, driving increased adoption among both merchants and consumers. Furthermore, mobile money has emerged as a key enabler of government services and financial assistance programs. Several African governments now utilize mobile money for salary payments, tax collection, and the distribution of social welfare benefits, ensuring that funds reach beneficiaries quickly and securely.

This has been particularly impactful in times of crisis, such as during the COVID-19 pandemic, when mobile money facilitated emergency relief efforts by providing direct cash transfers to affected populations. Both registered accounts with 13% in 2021 and active 30-day accounts with 13% in 2020 peaked at the time of national lockdowns.[11]

[9] GSMA (Industry Report on Mobile Money 2024), p. 11
[10] GSMA (Industry Report on Mobile Money 2024), p. 10
[11] GSMA (Industry Report on Mobile Money 2024), p. 18, figure 4

The COVID-19 pandemic acted as a booster for mobile money adoption, surpassing the forecast of 2023 by over 61% in transaction volumes and 35% in transaction values.[12]

Despite its remarkable success, mobile money in Africa still faces challenges, including high transaction fees, regulatory inconsistencies, and limitations in cross-border interoperability. Addressing these challenges will be crucial in ensuring continued growth and accessibility, particularly as Africa moves towards greater economic integration through initiatives like the African Continental Free Trade Area. While cross-border transactions remain a challenge, recent developments suggest that blockchain technology could complement mobile money solutions by reducing remittance costs and enhancing transaction transparency, fostering further regional and international integration.

2.2 Socioeconomic Impact of M-Pesa on local economies

The economic impact of M-Pesa extends beyond individuals and government financial transactions, playing a crucial role in supporting micro, small and medium-sized enterprises. A significant impact of M-Pesa has been its role in enhancing financial resilience among rural populations. Through microfinance partnerships, introduced by the Orange Bank Africa, users can access short-term loans and savings products directly via their mobile phones in Côte d´Ivoire. In Côte d´Ivoire alone, the potential value of this market is estimated to exceed $2.4 billion USD. Orange Bank Africa already distributed more than 2.4 million digital microcredits between 2020 and 2023, so called “Tik Tak” loans, which offer instant access to credit. Those credits range from $8 to $1600 USD and are repayable within 30 to 90 days at a maximum annual interest rate of 15%, comparable to local banks.[13] Before the introduction of mobile money, many small businesses relied heavily on cash transactions, which posed risks related to theft, fraud, and limited financial traceability. With M-Pesa, businesses can now securely receive payments, track transactions, and access credit facilities, fostering entrepreneurial growth and economic development.

An additional benefit is that more adults are now able to access and utilize their savings through mobile money accounts. In 2021, 26% of adults in the region saved formally, marking an 11% increase since 2017 and indicating a structural shift toward financial inclusion. Countries like Kenya have seen particularly strong adoption: while overall saving rates remained stable at around 70%, the share of adults saving formally rose

[12] GSMA (Industry Report on Mobile Money 2024), p. 36, Box 1
[13] GSMA (Industry Report on Mobile Money 2024), p. 30

by 18%, with 35% of savers relying exclusively on mobile money accounts. Women especially have benefited, with usage of mobile money savings products exceeding that of formal bank accounts by a factor of four in some countries, such as Senegal. Mobile money offers not only a convenient alternative to bank-based saving, but also lowers barriers related to cost, distance, and social norms. As mobile savings products such as M-Pesa continue to expand, providers report strong profitability: between 2019 and 2023, the share of operators reporting positive earnings before interest, tax, depreciation and amortization (EBITDA) rose from 60% to over 73%. Even without interest-bearing features, mobile savings accounts have encouraged consistent saving behavior. Between September 2022 and June 2023, the number of unique mobile money users saving funds increased by 38%, while gender-disaggregated data showed a 98% increase in female savers.[14]

Despite its successes, M-Pesa still faces several challenges, including transaction fees, interoperability limitations with international financial systems, and regulatory hurdles. The high cost of transactions can disproportionately affect lower-income users, limiting the full potential of mobile money in promoting financial inclusion. Additionally, regulatory restrictions in some African countries have hindered the expansion of M-Pesa beyond Kenya.

2.3 Comparison of M-Pesa to the traditional payment systems Swift & VISA

Even though M-Pesa gained recognition in the past decade, international money transfers in the agricultural trade sector, especially between Europe and Sub-Saharan Africa, are typically still routed through traditional financial infrastructures like the Swift network or global payment processors such as Visa. However, these methods are often associated with significant transaction costs, high conversion rates and delays.

Swift, founded in 1973, has become the global standard for secure financial messaging between banks and financial institutions, facilitating the execution of cross-border transactions. As of 2023, Swift connects over 11.500 financial institutions across more than 200 countries and processes approximately 47.6 million financial messages per day, amounting to over 15 billion transactions annually. In terms of value, Swift enables the movement of an estimated $5 trillion USD daily, primarily between institutional and commercial entities.[15]

[14] GSMA (Industry Report on Mobile Money 2024), pp. 45,48,49
[15] Swift (Annual Review 2023), p. 6

Most major banks and financial institutions rely on the Swift network, making it the underlying system for most online money transfers, even when not initiated directly through a bank. According to the World Bank, international transfers to Africa are additionally 3% over the global average.[16] These costs can escalate further when exchange rates occur or multiple correspondent banks are used in the process, each deducting their own fee before the funds reach the final recipient. In a scenario where a European importer transfers $1000 USD to a coffee cooperative in Ethiopia, total costs can easily exceed $50 USD, resulting in a 5% loss before the funds even reach the beneficiary. Each payment typically passes through multiple correspondent banks in a chain-like process, which introduces delays and additional cost layers. In developing countries, local banks often lack direct access to Swift, requiring further intermediaries, each with their own compliance, foreign exchange margin, and processing fees. Moreover, due to "Anti-Money Laundering" and "Know Your Customer" (KYC) protocols, transactions are subject to intense scrutiny, sometimes resulting in unexpected holds or rejections.

Visa, established in 1958, also plays a central role in card-based and digital payments and represents a similar case. Visa-based transactions also involve hidden costs in the form of merchant fees, interchange fees, and potential currency conversion charges. Standard fees typically range from 0.15% up to 1% of the transaction amount, with minimum charges starting at €7.90 EUR and capped at €51.90 EUR, depending on the transfer model. For transfers under €250 EUR, flat-rate fees of €10 to €12.50 EUR are common, with incoming international transfers also subject to additional charges between €1.50 and €10 EUR. Service providers may charge an additional 2.5–3% in fees for currency conversion.[17] This could result in a total cost of up to 5% for a $1000 USD payment, or $50 USD per transaction, comparable to Swift. While Visa is often more accessible through mobile-based payment apps and merchant terminals, it still requires participants to be integrated into the formal financial system. This presents a major barrier in rural Africa, where many coffee farmers remain unbanked and lack access to the infrastructure needed to receive digital Visa payments.

Additionally, the pricing model used by Visa and other card networks is not optimized for microtransactions. A flat minimum fee per transaction can disproportionately affect low-value payments, making it financially unfeasible to process small-scale, high-frequency transactions. Visa processed approximately 234 billion transactions in fiscal year 2024, up from 213 billion in 2023. These transactions contributed to a net revenue

[16] Veem (International Transfer Fees)
[17] comdirect (FAQ Auslandsüberweisungen)

of $35.9 billion USD, marking a 10% increase year-over-year. Specifically, international transaction revenue alone totaled $12.7 billion USD, reflecting the growing reliance on Visa's infrastructure for cross-border payments.[18]

Visa and Swift have long dominated the landscape of international payment systems, and these figures show that both will likely continue to be a global leader in the payments space. Despite their widespread adoption, traditional payment systems and even regionally dominant platforms like M-Pesa offer limited efficiency when it comes to fast, low-cost, and seamless cross-border transactions. High transaction fees, currency conversion barriers, regulatory fragmentation, and a lack of interoperability continue to hinder the scalability of these systems for inclusive, international financial flows, particularly in the context of small value transfers common in agricultural trade. Moreover, the need for formal bank accounts and access to financial infrastructure still excludes large segments of the rural population from participating in global supply chains efficiently. These identified research gaps form the basis for the following technological evaluation of blockchain systems in the context of decentralized agricultural finance.

3. Fundamentals of Blockchain Technology

3.1 Functionality and Core Features of Blockchain

The internet was initially envisioned as a decentralized network, but in practice, financial systems still rely on centralized authorities such as banks, governments, and corporations. These entities manage data through traditional processes that are prone to human error and manipulation. Blockchain technology emerged as a response to these challenges, offering a decentralized and secure way to record and verify transactions without the need for intermediaries.

Blockchain is a transformative technology with the potential to redefine various industries by providing secure, transparent, and decentralized solutions. As adoption grows and technology advances, blockchain is set to reshape the way data, transactions, and digital identities are managed, paving the way for a more transparent and efficient digital economy.

The projected growth of the global blockchain market underscores the increasing relevance and long-term viability of blockchain-based infrastructures, particularly for transactional use cases across industries. As illustrated in the comparative forecast, all three research institutions, Fortune Business Insights, Grand View Research, and

[18] Visa (Annual Report 2024)

Statista anticipate a sharp and sustained increase in blockchain adoption over the coming decade. By 2030, market size projections range between approximately $1.200 and $1.500 billion USD, reflecting compound annual growth rates that far exceed those of traditional digital technologies.[19]

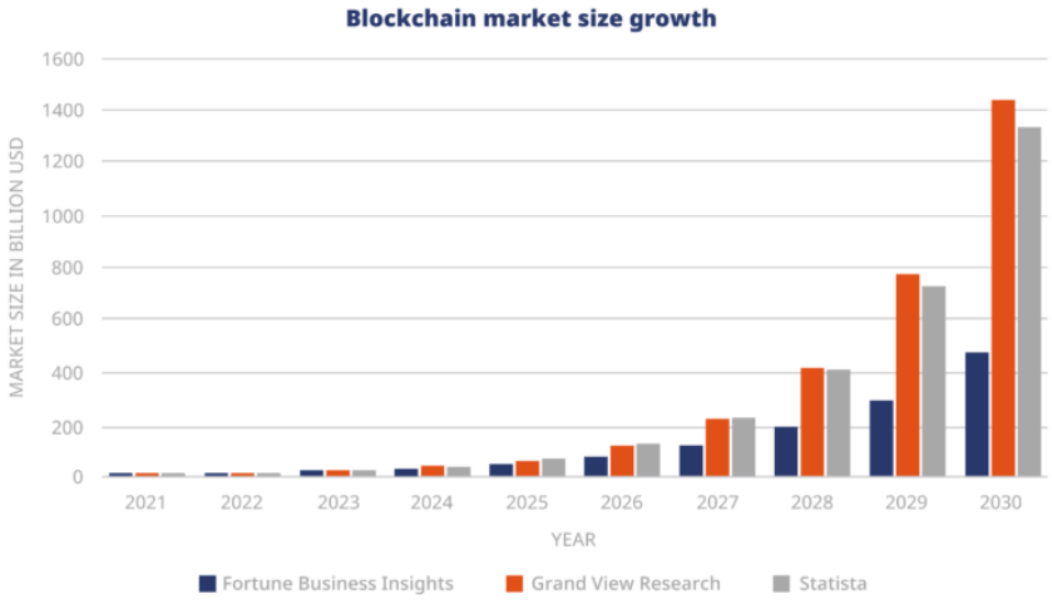

Image 2: Krusche & Company (Blockchain Entwicklungssektor - Statistiken und Fakten)

In this context, it becomes clear that blockchain does not only function as a technical innovation but as an enabler of new economic and social structures. Its core functionality namely decentralization, immutability, and transparency form the basis for use cases in fields like international supply chains, decentralized finance or digital certification.[20]

The concept of blockchain was first introduced in a whitepaper published in late 2008 by an individual or group using the pseudonym Satoshi Nakamoto. This document outlined the principles of a new form of digital currency called Bitcoin. Since then, every cryptocurrency developed has been built upon the foundational ideas presented in that whitepaper. Nakamoto´s primary objective was to create a form of digital money that would facilitate online transactions between individuals across the globe without the need for third-party intermediaries such as credit card companies or traditional payment systems. This required solving a critical issue known as double spending, where a user could attempt to use the same digital currency multiple times.

[19] Krusche & Company (Blockchain Entwicklungssektor - Statistiken und Fakten
[20] Cointelegraph (Blockchain fundamentals)

The solution Nakamoto proposed was a network that continuously verifies the flow of Bitcoin, which became the foundation of the blockchain.[21]

A blockchain is a distributed and tamper-proof ledger that maintains records across a network of computers. Unlike conventional databases managed by a single organization, blockchain ensures data integrity through collective validation by participants. This decentralized model fosters trust without requiring a central governing body. Transactions within a blockchain are grouped into blocks, each linked to the previous one by a unique cryptographic identifier known as a hash. This sequential structure forms an immutable chain, making it virtually impossible to alter past records without modifying all subsequent blocks.[22]

Every Bitcoin transaction is recorded and verified by a decentralized network of computers worldwide, independent of any government, corporation, or individual control. The database that stores all transaction information is known as the blockchain. The operational process of a blockchain, using a Bitcoin transaction as an example would proceed as follows. The process begins when a user initiates a transaction, for instance, transferring a certain number of bitcoins from one wallet address to another. This transaction request is then broadcast to a peer-to-peer network of nodes, which collectively maintain and validate the ledger. Validation is performed through cryptographic algorithms in a process known as mining. Miners, specialized nodes in the network compete to solve complex mathematical problems that verify the legitimacy of the transaction. Miners contribute computational power to process transactions, and in return, they are rewarded with small amounts of Bitcoin. Upon successful validation, the transaction is grouped with others to form a new block. This block is then appended to the end of the existing blockchain, thereby extending the chain in a linear and chronological manner. Once integrated, the data becomes immutable and visible to all participants in the network. Each block contains three core components: a set of confirmed transactions, a timestamp, and a cryptographic hash that links it to the previous block.[23] This innovation of decentralization not only eliminated the need for centralized trust, but also introduced a new paradigm for data management, applicable far beyond financial transactions.

For this thesis, understanding these technological fundamentals is crucial for assessing the suitability of blockchain in creating fair, efficient, and verifiable payment systems for Ethiopian coffee producers.

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[21] Coinbase (What is a blockchain)
[22] Bitpanda (Blockchain Fundamentals)
[23] Bitpanda (Blockchain Fundamentals)

3.2 Smart Contracts

An essential feature that extends blockchain´s utility is the implementation of smart contracts. These are self-executing agreements with the terms directly written into code and deployed on blockchain platforms. Once predefined conditions are met, the contract executes automatically. They perform functions such as transferring assets, validating data, or triggering additional actions without further human intervention. Their use fosters a high level of trust and transparency, as all contract details and transactions are stored immutably on the blockchain. Smart contracts operate according to "if-this-then-that" logic: for example, if a delivery confirmation is received, payment is automatically released to the supplier. The code and its execution are verified by all nodes in the blockchain network, ensuring trust in the outcome without requiring central oversight. This makes them especially useful in decentralized ecosystems, where trust among participants cannot be assumed. Smart contracts offer several advantages. First, they reduce the need for intermediaries, which lowers transaction costs and speeds up processing times. Second, they increase transparency, as all contract terms and outcomes are publicly recorded and verifiable on-chain. Third, they offer high reliability, once deployed, the contract executes exactly as programmed. However, there are also disadvantages. First, smart contracts are immutable: coding errors cannot be corrected after deployment, potentially leading to financial or legal risk. A related problem is the prior testing of smart contracts, which usually requires additional test systems to identify and remove programming errors before they are implemented. Second, they rely on accurate data input, meaning that off-chain data sources must be trustworthy. Third, legal enforceability remains unclear in many jurisdictions, making their use in regulated environments challenging.[24]

[24] Bitpanda (Smart contracts)

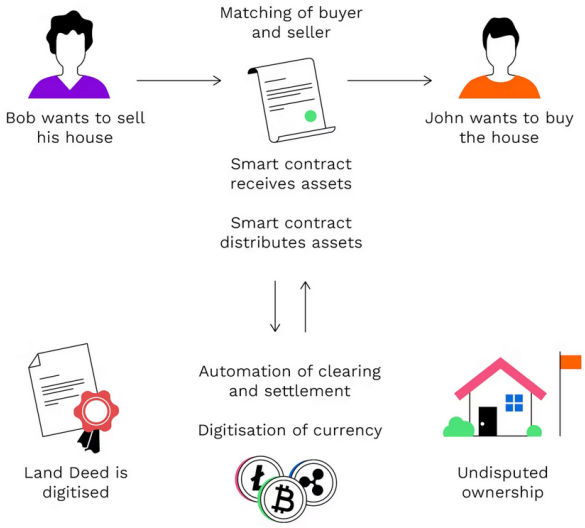

Image 3: Bitpanda (Smart contracts)

The graphic above illustrates how a smart contract can automate the exchange process between a buyer and a seller, in this case, during a property transaction. Once Bob and John agree to trade assets (the house and payment), the smart contract functions as a trusted intermediary: it receives and verifies both parties´ inputs, then automatically distributes the assets accordingly. The land deed is digitized and transferred to John, while the payment is settled digitally to Bob, ensuring instant, secure, and undisputed ownership without the need for traditional intermediaries such as notaries or banks. This example demonstrates the core benefits of smart contracts: automation, transparency, and efficiency in complex, high-trust transactions.

Moreover, since smart contracts on public blockchains are accessible to all, data sensitivity and privacy must be managed with care. Also, the transparency inherent in public blockchains means that sensitive contract details are visible to all, which may not be desirable in certain business contexts.

Smart contracts are widely used across multiple sectors. In finance, they underpin decentralized lending platforms and automated trading protocols. In supply chain management, they automate payments, track goods, and ensure regulatory compliance.[25] In the context of this thesis, smart contracts are particularly relevant for enabling transparent, automated compensation systems for farmers, enforcing Environmental, Social and Governance (ESG) standards, and creating traceable audit trails in agricultural trade.

3.3 Decentralized Applications (DApps)

Decentralized applications (DApps) are blockchain-based software programs that operate without central authority, relying instead on smart contracts and distributed

[25] Bitpanda (Smart contracts)

ledger technology to function autonomously. Unlike conventional applications, which are hosted on centralized servers and controlled by a single entity (image on the top), DApps are deployed on public blockchains and are maintained by a network of nodes, making them censorship-resistant and tamper-proof (image on the bottom).[26]

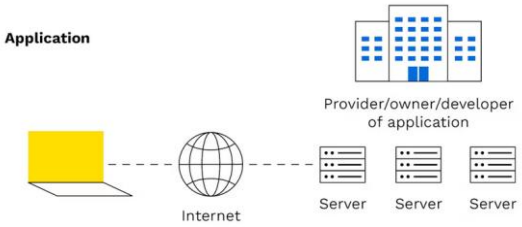

Image 4: Bitpanda (DApps)

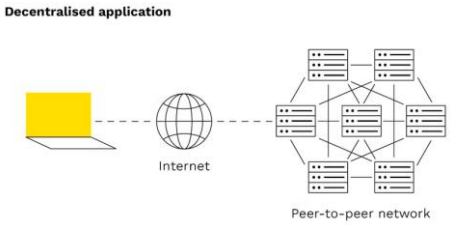

Image 5: Bitpanda (DApps)

Structurally, DApps consist of three core components: a user interface (frontend), the smart contract logic (backend), and the blockchain infrastructure for data storage and validation. These elements work together to execute application functions without intermediaries. A key difference from traditional apps is that once a Dapp´s smart contract is launched on-chain, it cannot be altered, providing high transparency but also requiring careful development and auditing in advance. The primary advantages include high transparency, since all interactions are publicly recorded on the blockchain, and greater user autonomy, as participants interact directly with the protocol without centralized control. Furthermore, because DApps are open-source and decentralized, they are resistant to censorship and single points of failure. However, challenges remain. First, because smart contracts are immutable, errors or security vulnerabilities in the code cannot easily be fixed post-deployment. Second, the user experience of DApps often lacks the smoothness of centralized apps, as users must manage private keys, gas fees, and decentralized wallets, which can pose barriers to adoption. Despite these drawbacks, DApps present a robust technological foundation for rethinking how data, value, and governance can be managed digitally. In global trade applications, they can streamline operations, lower costs, and create

[26] Bitpanda (DApps)

trust-minimized systems that are especially relevant for emerging markets and underbanked communities. DApps are increasingly used in finance (DeFi), digital identity, supply chain traceability, voting systems and gaming.[27]

As emphasized by platforms like Coinbase, poorly designed or unaudited decentralized applications can expose users to scams and exploitation.[28] Cybersecurity and fraud remain critical concerns especially across the African continent, where the financial damage caused by cybercrime is escalating rapidly. According to INTERPOL, cybercrime inflicted economic losses exceeding $4 billion USD in 2021, equivalent to approximately 10% of Africa´s total GDP, making the region particularly vulnerable and highlighting the urgent need for secure digital infrastructure as financial technologies expand.[29] The following chapter applies these blockchain principles to a comparative evaluation of real-world platforms such as Ethereum, VeChain, and Solana.

4. Comparative Analysis of Blockchain Platforms for Supply Chains and Payments

4.1 Ethereum: Smart Contracts and Historical Significance

4.1.1 Core Concepts of Ethereum

Ethereum, launched in 2015 by Vitalik Buterin, represents a significant advancement in blockchain technology, building upon the foundational principles introduced by Bitcoin. It enables the development and deployment of smart contracts and decentralized applications, offering a flexible infrastructure for a wide range of use cases, including finance, supply chain tracking, gaming, and digital identity.[30]

The platform´s native cryptocurrency, Ether (ETH), serves both as a means of transaction and as a form of “gas” to compensate network participants for computational effort. Thanks to its flexibility and developer ecosystem, Ethereum supports a wide range of use cases. In finance, it enables decentralized lending, trading, and asset management through Decentralized Finance (DeFi) protocols. In the creative economy, Ethereum powers non-fungible tokens, which represent unique digital assets such as artwork or certifications. Additional applications include digital identity management, supply chain traceability, gaming, governance mechanisms, and

[27] Bitpanda (DApps)
[28] Coinbase (Decentralized Applications)
[29] McKinsey & Company (African fintech leaders)
[30] Ethereum (What is Ethereum)

decentralized insurance. These diverse use cases demonstrate Ethereum's role as a foundational layer for a decentralized internet infrastructure, also referred to as Web3.[31]

As the core infrastructure layer of Ethereum, the Ethereum Virtual Machine (EVM) plays a critical role in maintaining consensus and ensuring the reliability of the decentralized ecosystem. EVM is the decentralized computational engine that powers the Ethereum blockchain. It acts as a global runtime environment for smart contracts, executing code exactly as programmed without downtime or third-party interference. Every Ethereum node runs the EVM locally, ensuring that all transactions and contract executions are validated uniformly across the network. This guarantees a consistent and secure environment for deploying decentralized applications. EVM is also Turing-complete, allowing developers to implement complex logic and business rules into smart contracts using languages like Solidity. To ensure the fair and secure use of network resources, Ethereum employed a gas system. Gas acts as a unit of computational cost, assigned to every operation executed by the EVM.[32]

Originally, Ethereum relied on a Proof-of-Work consensus mechanism, similar to Bitcoin, in which miners competed to validate transactions by solving computational puzzles. However, due to the growing need for energy efficiency and scalability, Ethereum transitioned to a Proof-of-Stake system through an upgrade known as "The Merge" in 2022. Under Proof-of-Stake, validators are chosen based on the amount of Ethereum they stake, significantly reducing the environmental impact and increasing transaction throughput. This shift has aligned Ethereum more closely with sustainability goals and real-world scalability requirements.[33] The different consensus mechanisms are explained in detail in Appendix A.

4.1.2 Advantages and Disadvantages of Ethereum

Ethereum´s role as a pioneering smart contract platform has significantly influenced the whole blockchain industry. However, while Ethereum is highly versatile and widely adopted, it also faces technical and economic challenges that impact its efficiency and scalability. This section explores Ethereum´s key advantages and disadvantages, providing a balanced evaluation of its strengths and limitations in the context of supply chain finance and blockchain-based payment systems.

[31] Bitpanda (Ethereum)
[32] Coinbase (Ethereum Virtual Machine)
[33] Bitpanda (Ethereum)

One of Ethereum´s most significant advantages is the notable strength of Ethereum is its robust developer community and continuous innovation. As one of the largest and most widely used blockchain networks, Ethereum has an active ecosystem of developers, researchers, and enterprises that contribute to its ongoing improvement.

Ethereum´s widespread adoption is reflected in its impressive network activity and developer engagement. More than 4.000 decentralized projects have been built on the Ethereum blockchain, leveraging its smart contract capabilities and infrastructure. As of today, over 53 million smart contracts have been deployed, facilitating a wide range of decentralized services. In the creative economy, Ethereum has enabled significant monetization opportunities, with content creators earning $3.5 billion USD in 2021 alone. Furthermore, the network processes over 12 million transactions per day, underscoring its scalability and relevance as the leading platform for decentralized applications. This strong developer support has led to frequent upgrades, such as Ethereum 2.0. The Ethereum Improvement Proposal system further allows for ongoing protocol enhancements, ensuring that Ethereum adapts to industry needs and technological advancements.[34]

Another advantage is Ethereum´s network effects and widespread adoption due to its long existence compared to newer blockchains. As one of the first smart contract platforms, Ethereum has established itself as the dominant blockchain for decentralized applications. Many high-profile blockchain projects, including decentralized finance protocols (e.g. Uniswap or Aave) and supply chain transparency solutions like Farmer Connect (see Appendix C) are built on Ethereum. Its established reputation and integration with various industries make Ethereum a trusted and widely recognized platform for enterprises and developers alike. In contrast, newer blockchain platforms often struggle to achieve the same level of adoption and credibility, giving Ethereum a significant competitive edge.

Despite its numerous advantages, Ethereum also faces several challenges that impact its usability and scalability in high-demand industries like global supply chain finance. Ethereum´s high transaction costs, which fluctuate based on network demand, can somehow be unpredictable, causing network congestion and high transaction fees during peak usage.[35] Although the Ethereum 2.0 upgrade transitioned the network to Proof-of-Stake, scalability challenges remain, particularly in high-frequency transaction environments like payments for Ethiopian coffee farmers. Competing

[34] Ethereum (What is Ethereum)
[35] Ethereum (Gas)

blockchains often offer higher throughput and lower transaction fees, making Ethereum less suitable for high-speed financial applications.

To address these limitations, Ethereum has seen the emergence of Layer-2 scaling solution protocols that operate on top of the Ethereum main chain (Layer 1) to increase transaction throughput and reduce costs. These include Optimistic Rollups and Zero-Knowledge Rollups, which function by bundling multiple transactions into a single batch that is then submitted to the Ethereum main network as a single transaction. This bundling significantly reduces the computational load on Layer 1 and allows users to share the associated gas fees across many transactions. Optimistic Rollups assume transactions are valid by default and only perform computations if fraud proof is submitted within a given time frame. This model offers high scalability and is well suited for general-purpose applications, although withdrawal delays can occur due to the fraud challenge period. In contrast, Zero-Knowledge Rollups rely on cryptographic proofs to verify the validity of a transaction batch before submission to Layer 1, ensuring faster finality and lower latency, making them more suitable for applications requiring higher security and real-time execution.[36]

By moving most of the transaction processing off-chain and only using Ethereum´s main network for final settlement and security guarantees, these Layer-2 solutions can reduce gas costs by over 90% in some cases. Average transaction costs on the Ethereum blockchain are around $0.11 USD and on Ethereum-backed Layer-2 networks around $0.0001 USD.[37] However, their adoption is still in progress, and many decentralized applications remain dependent on Ethereum´s base layer, where fees can remain volatile and economically inefficient. As these technologies mature and become more integrated, they hold significant promises for enabling affordable and scalable blockchain-based payment systems in sectors like agriculture and global supply chains.

Another disadvantage is Ethereum´s regulatory and security challenges. While Ethereum is a decentralized and permissionless network, its involvement in financial transactions and tokenized assets has attracted increasing scrutiny from regulators worldwide. Issues such as money laundering, tax compliance, and financial fraud have led governments to impose stricter regulations on cryptocurrency-based transactions, affecting the adoption of Ethereum. Additionally, Ethereum´s smart contract vulnerabilities have been exploited in various hacks and security breaches, demonstrating the risks of automated financial contracts without proper auditing and

[36] Ethereum (Ethereum Layer-2 Learn)
[37] Ethereum (Ethereum Layer-2)

safeguards. While Ethereum´s security is improving, regulatory uncertainty remains a key concern for businesses looking to integrate blockchain-based payment solutions.

4.2 VeChain: Specialized Supply Chain Blockchain

4.2.1 Core Concepts of VeChain

VeChain is a blockchain platform developed specifically to improve business processes and enable transparent information flow, efficient collaboration, and high-speed value transfers. Originally launched in 2015 by Sunny Lu, former CIO of Louis Vuitton China, VeChain was designed to meet the needs of enterprises seeking reliable, scalable, and secure blockchain infrastructure to optimize supply chains and logistics operations. Unlike other public blockchains that focus on decentralization and permissionless use, VeChain adopts a business-first approach, incorporating both governance and technical frameworks that align with industry requirements.[38]

A defining feature of VeChain´s architecture is its dual-token system, consisting of VeChain Token (VET) and VeThor Token (VTHO). VET serves as a store of value and is used for staking and governance purposes, whereas VTHO is consumed as "gas" to pay for smart contract executions and transactions on the network. This model separates utility from value transfer, allowing predictable transaction costs and preventing network congestion during periods of high usage. By design, this structure improves operational stability and encourages long-term platform adoption by enterprises. VeChain positions itself as a highly efficient and sustainable blockchain solution tailored for scalable enterprise applications. Since its launch in 2018, the VeChainThor blockchain has maintained 100% uptime, with an average block time of just 10 seconds and transaction costs consistently below $0.01 USD. To date, the platform has processed over 300 million contract clauses, underscoring its operational maturity.[39]

One of its key strengths is the seamless integration of Internet of Things devices, which enables the collection and recording of real-time data such as location, temperature, and handling conditions of goods. VeChain´s blockchain is utilized by businesses to enhance the traceability and management of critical information and operational processes across supply chains. The platform has already been adopted by several global corporations, including PricewaterhouseCoopers (PwC) for audit and compliance purposes, LVMH Moet Hennesy for tracking the authenticity of luxury

[38] Bitpanda (VeChain)
[39] VeChain (Technology)

goods, and Bayerische Motorenwerke (BMW) for preventing odometer fraud in used vehicle sales.[40]

In summary, VeChain´s technical architecture, built around a Proof-of-Authority consensus, dual-token model, and native enterprise toolset, provides a reliable and efficient blockchain environment for industrial applications while serving a high level of sustainability. Its ability to integrate real-world data, automate compliance processes, and ensure secure information exchange positions are a strong solution for sectors where transparency, accountability, and traceability are essential. While its level of decentralization is lower than that of other blockchains, this trade-off enhances its suitability for commercial and regulatory use cases.

4.2.2 Advantages and Disadvantages of VeChain

VeChain positions itself as a leading force in merging blockchain innovation with global sustainability objectives. Recognizing the urgency of climate change, environmental degradation, and social inequality, VeChain´s mission is to create scalable, collective impact by enabling individuals and institutions to make informed, responsible decisions in their daily lives. Central to this approach is the VeChainThor blockchain, which ensures high scalability, low energy consumption, and network security. With an annual carbon footprint of just 4.46 tons CO_2e per year and a per-transaction electricity consumption of 0.000216 kWh, VeChain ranks among the most energy-efficient blockchains globally, consuming only 0.04% of the energy of conventional networks. In addition to its technological infrastructure, VeChain advocates for a new sustainability paradigm driven by Web3 technologies. Through decentralized governance structures such as Decentralized Autonomous Organizations (DAOs), tokenization of societal and environmental value, and enhanced transparency and accountability, blockchain becomes a foundation for rethinking how sustainability is measured, verified, and incentivized. Smart contracts and decentralized applications further enable efficient resource allocation and operational optimization, reducing waste and increasing traceability.[41]

By actively collaborating with industry partners across sectors, VeChain fosters the development of practical, blockchain-based sustainability solutions. Its collaboration with Walmart China in 2019, for instance, showcases how VeChain´s blockchain can be used to enhance supply chain traceability and build consumer trust. VeChain partnered with Walmart China to enhance food safety and transparency within the

[40] Bitpanda (VeChain)
[41] VeChain (Sustainability)

retail giant's supply chain. This collaboration led to the development of the Walmart China Blockchain Traceability Platform, built on the VeChainThor blockchain. The platform enables Walmart China to track products through their supply chain, allowing consumers to scan products on shelves and access detailed information such as the source, product inspection reports, and logistics processes. This initiative addresses food safety concerns and enhances consumer trust by providing transparent and verifiable product information. The platform has processed over 200 million transactions, underscoring its scalability and the successful integration of blockchain technology in retail operations.[42]

Despite these strengths, VeChain also faces several limitations. A major concern is centralization due to the Proof-of-Authority model that relies on a limited number of 101 authority master nodes. This design significantly enhances the network´s scalability and transaction throughput but simultaneously introduces a relatively high degree of centralization and contradicts blockchain´s decentralized ethos. If one or more validators are compromised or act dishonestly, the network´s integrity could be at risk. Therefore, data input quality remains a critical vulnerability. As a result, the reduced validator pool raises concerns regarding vulnerability to collusion and diminished resistance to network manipulation.[43] If inaccurate or manipulated data is recorded at the source, it becomes permanently stored and trusted by downstream actors. Ensuring data accuracy requires robust verification processes at the point of data entry, which can be resource-intensive and may not always be foolproof. Without reliable verification processes at the point of entry of such information stored on the blockchain, the entire transparency objective of the blockchain can be undermined. This concern is especially important for international supply chains.

Although the requirement for identity verification and financial staking increases the accountability of authority nodes, the system inherently disadvantages users who choose not to undergo KYC procedures. To operate as an authority masternode within the VeChain network, participants must undergo full KYC verification and hold a minimum of 25 million VET tokens. These entry requirements create a high threshold that may discourage smaller stakeholders. Blockchains´ initial idea of anonymity is thereby also eliminated. This creates an asymmetry in governance rights and further highlights the trade-off between operational efficiency and decentralization within VeChain´s infrastructure.[44]

[42] ICOHolder (VeChain and Walmart China)
[43] Ledger (What is VeChain)
[44] Ledger (What is VeChain)

4.3 Solana: Primary Blockchain Solution for Coffee Supply Chains and Payments

4.3.1 Core Concepts of Solana

Solana, launched in 2020 by Anatoly Yakovenko, has rapidly established itself as a leading high-performance blockchain known for its focus on scalability, speed, and low transaction costs. Its technical architecture departs significantly many first- and second-generation blockchains such as Bitcoin and Ethereum by introducing innovative solutions designed to increase throughput without compromising decentralization or security. Central to Solana´s architecture is its unique consensus mechanism, which combines Proof of History with a version of Proof of Stake. This hybrid approach is key to achieving the network´s remarkable transaction capacity.[45]
Solana has established itself as a key infrastructure in the non-fungible token (NFT) space, powering marketplaces, digital collectibles, and creator-economies through low-cost, user-friendly minting processes. Its high throughput and minimal transaction costs of around an average of $0.00064 USD per transaction make Solana particularly attractive for decentralized finance (DeFi) applications, enabling fast and efficient execution of lending, trading, and liquidity protocols. Further areas of application include decentralized identity management, real-time payments using stablecoins, on-chain governance and Web3 gaming. Enterprise solutions for traceability, logistics, and environmental monitoring are also emerging, leveraging Solana´s infrastructure to meet compliance and sustainability demands.[46]
Unlike traditional blockchains where consensus requires validators to agree on the exact order and time of transactions, Proof of History introduces a cryptographic clock that creates a historical record proving that an event occurred at a specific moment in time. This is achieved through a sequential hashing process where each hash is dependent on the previous one. As a result, validators do not need to spend time and computational power to synchronize with each other before processing transactions. This timestamping mechanism allows for parallel transaction processing, significantly increasing throughput and reducing latency. In conjunction with Proof of History, Solana utilizes a Proof of Stake model, where validators are chosen based on the amount of Solana, the native cryptocurrency, they stake as collateral. Validators are responsible for validating transactions and securing the network. Staking not only aligns incentives among participants but also ensures energy efficiency when

[45] Bitpanda (Solana)
[46] Solana (Official Website)

compared to Proof of Work systems. Validators and delegators are rewarded for their participation, reinforcing the stability of the network. Solana´s technical performance is reflected in its ability to handle up to 50.000 transactions per second. This speed is achieved without the use of Layer 2 solutions, which are commonly necessary in other blockchains such as Ethereum to scale effectively.[47] But competition from Ethereum Layer 2 solutions continues to intensify, particularly as Ethereum advances its own scalability roadmap.

Solana´s architecture supports composability across applications, allowing developers to build interconnected services without performance trade-offs. From a developer ecosystem perspective, Solana benefits from robust institutional backing and an expanding community. The Solana Foundation actively supports developers with grants and technical resources. From foundational tutorials to advanced technical training, the platform provides accessible learning pathways designed to lower entry barriers and foster long-term engagement. Initiatives such as the Solana Bootcamp and Solana Bytes, serve as introductory modules for newcomers exploring blockchain development for the first time.[48]

In terms of real-world applicability, Solana´s performance metrics make it an attractive platform for blockchain-based financial systems, particularly in emerging economies where network fees and infrastructure costs are significant barriers. The speed, low transaction costs, and smart contract capabilities position Solana as a promising infrastructure for real-time payments to smallholder coffee farmers in Africa.

Solana´s technical stack also supports Layer 2 integrations and bridges to other chains, which could be vital for future interoperability between different blockchain systems and mobile payment platforms. Most important, Solana focuses on underserved and cash-based economies. To enable seamless integration of Solana-based applications into local economies, the ecosystem supports a growing number of on- and off-ramp providers. One popular provider is Moonpay, which is already offering services in Ghana and Kenya. Moonpay also operates in more than 40 countries all over the globe and supports transactions via Apple Pay, Google Pay, Credit, Debit, and Sepa.[49] These services allow users to convert fiat currencies into digital assets and thus offer the opportunity to participate in the global financial system. Such off-ramp providers play a vital role in connecting decentralized systems with local payment rails, ensuring that digital inclusion is not limited by geography or infrastructure.

[47] Coinbase (Solana)
[48] Solana (Developers)
[49] Solana (Solanaramp)

4.3.2 Advantages and Disadvantages of Solana

One of Solana´s most notable advantages are its exceptional transaction speed and scalability, which distinguish it from other public blockchains. As mentioned in the previous chapter, Solana can process up to 50.000 transactions per second, with finality times under one second.[50] With average fees as low as $0.00064 USD per transaction, the network enables cost-efficient processing, even during periods of high network usage.[51] It shows why Solana is ideal for real-time applications such as supply chain payments or retail microtransactions. Without additional Layer 2 solutions, the transaction and the overall performance are less complex and prone to errors. Due to the support of off-ramp providers, Solana can already be used for payments in several countries, including various currencies.

A second major strength is Solana´s energy efficiency when performing transactions. As illustrated in the comparative chart of electricity consumption, a single transaction on the Solana blockchain consumes significantly less energy than many everyday digital and physical activities. Compared to actions such as running a Google search, charging a smartphone, or even using an LED lightbulb for one hour, a Solana transaction requires only a fraction of the energy. Solana´s footprint is nearly negligible, underscoring its suitability for sustainable blockchain applications on scale. This high level of energy efficiency strengthens Solana´s positioning as a forward-looking infrastructure capable of supporting environmentally responsible use cases, particularly in the context of ESG-aligned global supply chains.[52]

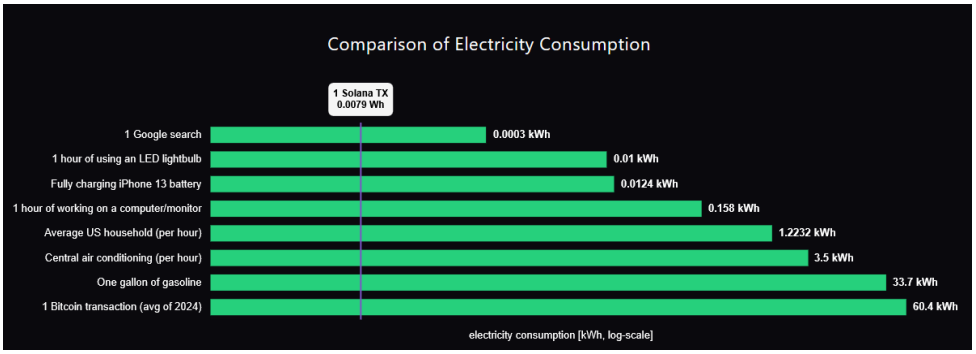

Image 6: Solana (Official Website)

Despite these impressive strengths, Solana also faces several important limitations. Since early 2022, the Solana network has experienced multiple instances of technical instability, including both partial and full-scale outages. The root causes of these disruptions have varied, ranging from vulnerabilities in the network´s software

[50] Coinbase (Solana)
[51] Solana (Official Website)
[52] Solana (Official Website)

architecture to external attacks such as denial-of-service and resource exhaustion. The most recent incident was triggered by a critical bug that led to an infinite loop condition within the validator system. As a result, validators became stuck processing the same block repeatedly, effectively halting transaction verification across the entire network. This pattern of repeated outages, amounting to more than a dozen major or partial service interruptions, has raised concerns about the operational resilience of Solana, particularly in contexts where continuous network availability is essential.[53]

Another concern is Solana´s validator centralization. Although Solana is fundamentally a decentralized network, it currently relies on a relatively small validator set of approximately 2.000 active nodes. The high hardware and bandwidth requirements associated with operating a validator make participation financially demanding, effectively limiting accessibility to well-resourced actors. As a result, Solana has faced criticism regarding its degree of decentralization, particularly in comparison to networks like Ethereum. Nonetheless, the Solana Foundation continues to invest in expanding validator diversity to enhance network resilience and decentral governance.[54]

4.4 Comparative Evaluation and Recommendation for Blockchain Selection

Based on the comparative analysis of Ethereum, VeChain, and Solana, Solana emerges as the most suitable blockchain platform for implementing a payment and traceability system within the Ethiopian coffee supply chain. Each platform offers unique advantages: Ethereum provides unmatched developer support and a mature ecosystem; VeChain is tailored to enterprise needs with strong integration in supply chain transparency; and Solana offers an optimal balance between speed, cost-efficiency, and scalability. However, the specific requirements of the proposed use case, namely, real-time payments, low transaction fees, energy efficiency, and mobile integration, make Solana the most compelling choice.

Ethereum´s broad adoption and smart contract flexibility make it a powerful infrastructure for complex decentralized applications. Its large developer base and Layer 2 innovations offer promising scalability improvements. Yet, high gas fees, variable transaction costs, and reliance on scaling solutions such as rollups, limit its efficiency for microtransactions in emerging markets. Additionally, Ethereum´s high

[53] Cointelegraph (Solana outage)
[54] Cointelegraph (Solana vs Ethereum)

infrastructure costs can hinder its accessibility for smallholder farmers and decentralized off-ramp providers in low-income regions.

VeChain, on the other hand, offers enterprise-level stability and sustainability. Its dual-token model ensures predictable transaction costs, and its native Internet of Things integrations support robust traceability use cases. However, VeChain´s highly permissioned Proof-of-Authority consensus, operated by a fixed group of only 101 validators, results in significant centralization. Furthermore, KYC and token-holding thresholds limit inclusivity and create governance asymmetries that are less aligned with the decentralized and accessible structure envisioned in this thesis.

In contrast, Solana combines high throughput with finality times under one second and consistent low transaction fees which are critical features for scaling automated payments to Ethiopian coffee farmers. Its energy footprint is minimal, making it an environmentally sustainable solution that aligns with ESG goals. The platform also demonstrates strong interoperability and a growing ecosystem of mobile-first on- and off-ramp providers, such as Moonpay, enabling seamless integration with local payment infrastructure like M-Pesa. Although Solana has faced criticism due to validator centralization and occasional outages, ongoing network upgrades and decentralization efforts aim to mitigate these concerns.

Given the specific context of agricultural value chains in Sub-Saharan Africa, characterized by small transaction sizes, mobile-first access, and the need for transparent, low-cost, real-time settlement, Solana provides the most practical and technically aligned blockchain infrastructure. Its performance, accessibility, and expanding ecosystem make it best positioned to support scalable and inclusive blockchain-based payment systems within the coffee supply chain. The Cost-benefit-analysis in chapters 6.2 and 6.3, is therefore focused on the Solana blockchain.

5. Legal Framework, Fair Trade and Market Dynamics based on the example of The Supply Chain Due Diligence Act

5.1 Objectives and Requirements of The German Supply Chain Due Diligence Act

The German Supply Chain Due Diligence Act, which came into effect on January 1, 2023, marks a pivotal shift in legal and ethical expectations for companies operating within and beyond Germany. Its main objective is to strengthen corporate accountability by mandating companies actively protect human rights and environmental standards throughout their global supply chains. In detail, companies

are required to establish internal responsibilities, implement risk management systems, conduct regular risk analyses, issue and publish a policy statement, embed preventive measures, take corrective action where necessary, set up complaint mechanisms, and ensure thorough documentation and reporting on supply chain management. Initially applicable to companies with more than 3.000 employees in Germany, the threshold was lowered to 1.000 employees as of January 1st, 2024. This extension significantly broadens the law´s reach, encompassing a wide spectrum of medium-to-large enterprises that maintain direct or indirect relationships with international suppliers, including those within the agricultural sector in Sub-Saharan Africa. Importantly, the law applies not only to a company´s internal operations but also includes direct contractual partners and, under certain risk-related conditions, even indirect suppliers, to ensure that companies do not avoid the law and their responsibility by using intermediaries within the supply chain.[55]

Beyond the national level, the Supply Chain Due Diligence Act aligns with broader European initiatives. On July 25th, 2024, the European Union adopted the Corporate Sustainability Due Diligence Directive (CSDDD), which aims to harmonize due diligence standards across member states. They have introduced new environmental due diligence obligations for companies, including measures to protect biodiversity, endangered species, marine ecosystems, and compliance with international environmental agreements. Additionally, firms are now required to adopt and implement a climate transition plan aligned with the Paris Agreement and the EU´s climate neutrality targets. This plan must demonstrate how the company's business model contributes to limiting global warming to 1.5°C.[56] These legal developments reinforce the need for companies to integrate scalable, verifiable, and tamper-proof systems for managing supply chain data and demonstrating compliance across international borders. To comply with the Supply Chain Due Diligence Act, companies are required to establish an effective risk management system that proactively identifies and evaluates human rights and environmental risks across their supply chains. This includes publishing a clear policy statement, implementing preventative and corrective measures, and creating an accessible complaints procedure through which affected parties can report violations. The legislation emphasizes the protection of core human rights, such as the prohibition of child labor, forced labor, and discrimination, and calls for fair wages and safe working conditions.

[55] Bundesministerium für Arbeit und Soziales (Lieferkettensorgfaltspflichtengesetz)
[56] Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit (Europäische Lieferkettenrichtlinie CSDDD)

Furthermore, the Supply Chain Due Diligence Act places environmental protection at its core, requiring companies to prevent significant environmental damage resulting from harmful practices like soil contamination, water pollution, or the improper disposal of waste. All companies within the scope are obligated to document their compliance efforts and submit an annual report to the Federal Office for Economic Affairs and Export Control (BAFA).[57]

In this context, blockchain technology has emerged as a potential enabler of efficient and tamper-proof ESG reporting systems. As highlighted in the GBBC Annual Report, The InterWork Alliance (IWA), provides organizations with the framework to integrate token-based services into everyday operations. By promoting interoperability and inclusivity across platforms and use cases, IWA supports the development of globally scalable and interconnected digital ecosystems.[58] By enabling immutable, decentralized, and time-stamped records of actions such as ethical sourcing, environmental compliance, and fair payment, these systems can support companies in aligning with Supply Chain Due Diligence Act obligations.

5.2 Implications and Challenges for International Supply Chain Stakeholders

The global implications of the Supply Chain Due Diligence Act are particularly relevant for international supply chains in the agricultural sector, such as coffee production. Companies with sourcing ties to smallholder farmers in countries like Kenya, Ethiopia, or Uganda are now under increased pressure to ensure that their supply networks adhere to Germany´s human rights and environmental standards. This requires reevaluating procurement policies, adapting supplier contracts, and improving auditing and transparency mechanisms. For many European importers of agricultural goods, especially those in the coffee industry, the law acts as both a challenge and an opportunity: it compels them to collaborate more closely with upstream producers to ensure ethical compliance, while also encouraging the adoption of modern technologies like blockchain to document and verify responsible sourcing practices. Consequently, German companies are increasingly incentivized to support their suppliers, particularly those in vulnerable regions, with training, investment, and technical tools that facilitate compliance. Once a proper system within the blockchain technology has been established and implemented, administrative work will be

[57] Wirtschaft & Menschenrechte (Faire Lieferketten)
[58] Global Blockchain Business Council (GBBC Annual Report 2024), p.17

eliminated nearly completely. The system could run automatically and be maintained or optimized with a small amount of effort and resources.

Monitoring and enforcement of the Supply Chain Due Diligence Act are handled by the BAFA, who also has the authority to impose substantial financial penalties for non-compliance. Companies that fail to meet their due diligence obligations can be fined up to €8 million EUR or up to 2% of their global annual revenue if they earn more than €400 million EUR. Moreover, companies facing fines above €175.000 EUR can be excluded from public procurement for up to three years.[59] While these enforcement mechanisms increase the legal pressure on corporations, many businesses report significant difficulties in implementing the law effectively, especially those with complex, multilayered supply chains that span diverse regulatory jurisdictions. For small-scale coffee farmers, this compliance burden can also be overwhelming and even lead to exclusion from international trade if not supported adequately by downstream partners. To mitigate these risks, companies are advised to establish collaborative frameworks with their suppliers, implement digital tools for real-time monitoring, and develop structured onboarding programs for suppliers lacking sufficient technological infrastructure. This connection between digital innovation and legal responsibility forms a central argument of this thesis.

One of the most critical issues in the practical implementation of the Supply Chain Due Diligence Act lies in translating legal obligations into measurable action. In sectors like agriculture, where smallholder farmers operate with limited digital infrastructure and minimal institutional support, compliance cannot be achieved through legal mandates alone. Instead, it requires a strategic shift in how companies engage with their upstream partners. Many European firms are beginning to recognize that one-off audits or paper-based assessments are insufficient to meet the law´s demands for continuous monitoring and proactive risk mitigation. As a result, there is growing interest in adopting digital technologies capable of automating due diligence reporting and providing immutable records of ethical sourcing practices.

Platforms such as Solana enable the creation of smart contracts and digital registries that can document every step of the supply chain “from crop harvesting to export” while ensuring that each transaction complies with predefined ethical and environmental criteria. These tools not only reduce administrative burdens but also facilitate a real-time, auditable trail of compliance that aligns with BAFA´s expectations for documentation and proof of action. All relevant data is stored and can

[59] Wirtschaft & Menschenrechte (Faire Lieferketten)

be checked by BAFA via the blockchain. This data cannot be manipulated in the company´s way to overcome the act. Despite its clear ambition to enforce ethical and transparent global supply chains, the practical implementation of the Supply Chain Due Diligence Act remains partially misaligned with the capabilities and logic of blockchain technology. While blockchain offers decentralized, tamper-proof, and verifiable documentation mechanisms that could theoretically fulfill the law´s requirements more efficiently than traditional systems, the current regulatory frameworks lack precise guidance on how such digital tools should be recognized or audited. This legal ambiguity creates uncertainty for companies that wish to adopt blockchain as a compliance tool, as it is unclear whether smart contract-based verifications or on-chain reporting mechanisms will be officially accepted as valid proof under the evolving compliance criteria. As a result, there is a growing need for legislative clarification and technological standardization to bridge this gap and enable a truly digitized and scalable approach to due diligence. Bureaucracy remains a major problem, especially in the European Union and towards cross-border trade regulations affecting agricultural imports.

While the Supply Chain Due Diligence Act does not mandate specific technologies or procedures, it establishes a clear expectation: companies must demonstrate that human rights and environmental standards are upheld not just in theory, but in practice and must provide evidence of it. In this context, blockchain technology emerges not as a legal requirement, but as a practical enabler of compliance. European importers dealing with fragmented, rural supply chains such as those in African coffee production face the challenge of establishing real-time transparency, data immutability, and audit-ready documentation.

Thus, corporate social responsibility frameworks must go beyond social reporting and include active support strategies, such as technical onboarding, infrastructure co-investment, digital training programs, and long-term partnership models. Only by building inclusive digital ecosystems can European importers fulfill both the letter and spirit of the Supply Chain Due Diligence Act and broader Corporate Social Responsibility (CSR) obligations. This expectation aligns with international sustainability norms and growing consumer pressure for transparent sourcing. Importers must therefore not only adopt blockchain technologies but also embed them within participatory structures that empower smallholder farmers to become active stakeholders in their own compliance journey. This transforms compliance from a top-down obligation into a collaborative value proposition and positions importers as catalysts for innovation and equity within global value chains.

5.3 Fair Trade and Ethical Sourcing in the German Coffee Market

The coffee industry is undergoing a rapid transformation driven by evolving consumer preferences, advancing technologies, and an increasing demand for sustainable practices. In Africa, where coffee has long-standing cultural and economic roots, these changes present new opportunities for producers, roasters, and entrepreneurs across the value chain. One of the most prominent shifts is the rise of specialty coffee, with consumers now seeking traceability, quality, and distinctive flavor profiles. This trend benefits African producers who can highlight the unique characteristics of their beans and appeal to global markets. Sustainability has also become a non-negotiable requirement; businesses must now invest in eco-efficient roasting equipment and ethical sourcing to remain viable. These global dynamics are reflected in key consumer markets such as Germany, where shifts in purchasing behavior and quality expectations are reshaping demand patterns and opening new pathways for sustainably and ethically sourced coffee.

Growing demand for Fair-Trade and ethical sourcing standards or products represents a longer-term transformation in consumer expectations and corporate responsibility. In the coffee sector, this is operationalized through minimum pricing models, social premiums, and long-term supply agreements that stabilize farmer incomes and promote sustainable practices. Nevertheless, the Fair-Trade landscape in Germany is marked by considerable heterogeneity. Numerous certifications and private standards coexist, each with varying requirements, credibility levels, and consumer recognition. This plurality has led to confusion and even skepticism among consumers, as well as to significant implementation disparities among suppliers. For example, while Fair-Trade International is widely recognized for its minimum price guarantee and social premium model, other schemes such as Rainforest Alliance place a stronger emphasis on environmental protection and biodiversity, often using a continuous improvement approach rather than fixed pricing mechanisms. Moreover, smaller cooperatives or producer groups in the Global South often struggle with the financial and administrative burdens of obtaining and maintaining certification, limiting the inclusiveness of such systems or higher revenue streams.

Legal developments obligate companies to take structured, evidence-based actions to identify and mitigate risks in their supply chains, going beyond the marketing narratives often associated with Fair-Trade labels. As a result, the line between ethical sourcing as a value-based differentiation strategy and as a compliance imperative is becoming increasingly blurred. For importers operating in the German coffee market,

this convergence of consumer expectations, regulatory obligations, and reputational risks presents both a challenge and an opportunity. On one hand, they must navigate complex compliance landscapes and respond to critical scrutiny. On the other, they are uniquely positioned to redefine value creation in the supply chain by anchoring it not solely in price or volume, but in transparency, accountability, and social equity. Fair-Trade, when integrated into a broader sustainability and risk governance strategy, can therefore serve as both a marketing asset and a compliance enabler.

The following graphic shown below marks the estimated revenue of the German coffee market, divided into roasted and instant coffee. According to Statista Market Insights, total coffee sales in Germany dropped significantly in 2020, reaching only €16.3 billion EUR, compared to €19.9 billion EUR in 2019. However, the market began to rebound in the following years, rising to €19 billion EUR in 2021 and €20.1 billion EUR in 2022. Most notably, in 2023, the German coffee market reached a new peak with estimated revenues of €23.3 billion EUR, the highest level in the past six years. This increase reflects both a resurgence in consumer demand and a continued preference for roasted coffee, which makes up most of total sales.

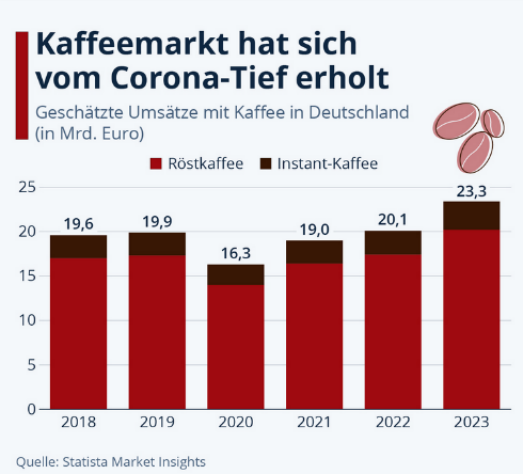

Image 7: Statista (Infografik – Umsatz Kaffee in Deutschland)

In 2023, total revenue from Fair-Trade products increased by 7.3%, reaching €2.34 billion EUR at retail price. With food accounting for 82% of total Fair-Trade revenue, coffee remains the most dominant product, representing 38.6% of overall Fair-Trade sales. On the second and third place are tropical fruits with 10,1% and textiles with 9,5%.[60]

Another statistic shows how revenue of the Fair-Trade coffee segment in Germany has also experienced substantial growth over the past decade. In 2011, total revenues amounted to €237.96 million EUR. By 2023, that figure had more than tripled to

[60] Forum Fairer Handel (Umsatz Fairtrade Deutschland 2023)

€837.13 million EUR, representing a growth of approximately 252%. Notably, this expansion persisted even through the COVID-19 pandemic, corresponding to the data regarding the whole coffee segment in Germany. Sales rose from €533.24 million EUR in 2019 to €540.89 million EUR in 2021, despite an interim dip of €492.04 million EUR in 2020. The steepest absolute increase occurred in the post-pandemic years, jumping from €705.45 million EUR in 2022 to over €837 million EUR in 2023. These figures underscore not only the resilience of the fair-trade segment but also a growing consumer commitment to ethically sourced coffee products.[61]

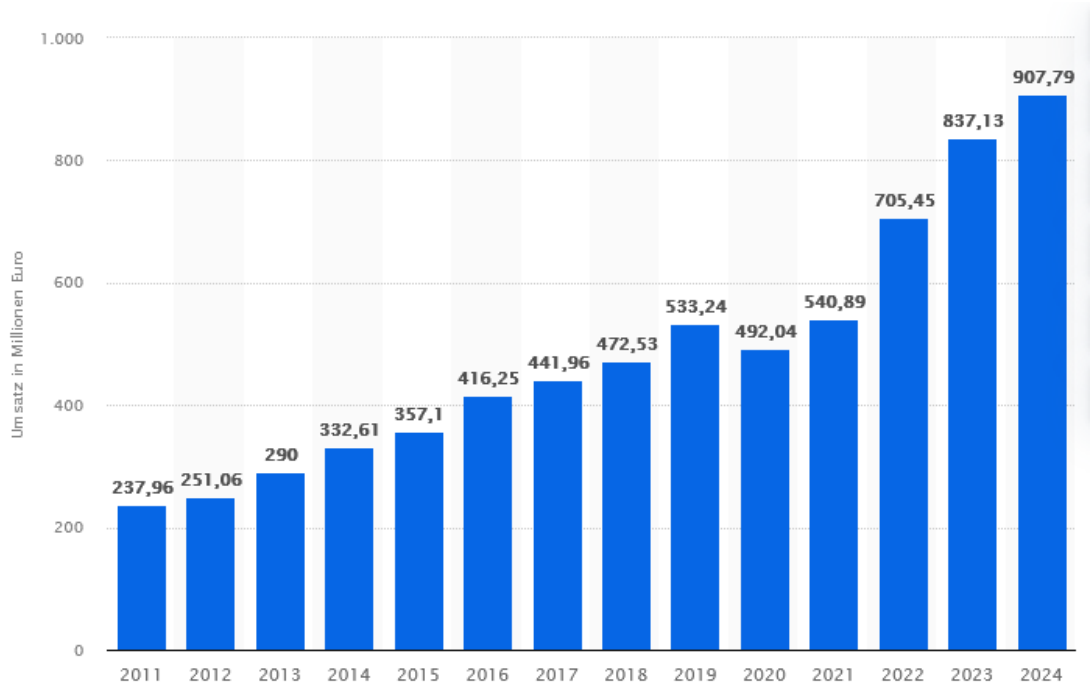

Image 8: Statista (TransFair: Umsatz Fairtrade-Kaffee 2011 bis 2024 Deutschland)

Despite the impressive growth of the Fair-Trade coffee segment, it is important to compare these numbers with the broader German coffee market. In 2023, total coffee revenues in Germany amounted to €23.3 billion EUR, whereas Fair-Trade coffee accounted for only €837.13 million EUR, representing a market share of just around 3.6%. This contrast underlines the enormous untapped potential for expansion. As consumers continue to prioritize ethical and sustainable consumption, and as regulatory frameworks increasingly demand verifiable sourcing practices, the Fair-Trade segment stands at the threshold of significant scaling opportunities. Bridging this gap requires not only consumer engagement but also structural innovations in sourcing, traceability, and certification.

[61] Statista (TransFair: Umsatz Fairtrade-Kaffee 2011 bis 2024 Deutschland)

5.4 Greenwashing and Consumer´s Demand for Transparency

As sustainability becomes a dominant theme in corporate responsibility and consumer behavior, the issue of greenwashing has emerged as a major concern within ethical sourcing discourse. Greenwashing refers to the practice of presenting products, services, or operations as more sustainable or ethical than they are, often by using vague claims, unverifiable certifications, or selective marketing strategies.[62] In global supply chains, this can manifest in exaggerated environmental performance indicators, misrepresented sourcing origins, or logos and labels that lack substantiated proof. As consumer awareness grows, so does skepticism toward these unverified sustainability claims.

A closer look at current consumer preferences reveals that transparency is not a niche demand but a mainstream expectation, especially among older and financially stronger demographics. According to a "YouGov" online survey, 74% of German consumers over the age of 55 actively support the demand for more transparent product information. Even in the age groups 35–44 and 44–54, this share stands at 62%, highlighting a consistent majority who value traceability and accountability in supply chains. Although the approval is slightly lower among younger demographics, 47% in the 18–24 group and 46% among 25–34-year-olds.[63] This may be less a sign of disinterest and more an indicator of brand fatigue due to vague sustainability claims or inaccessible information. As consumers age, gain purchasing power, and refine their ethical preferences, the demand for transparency increases significantly.

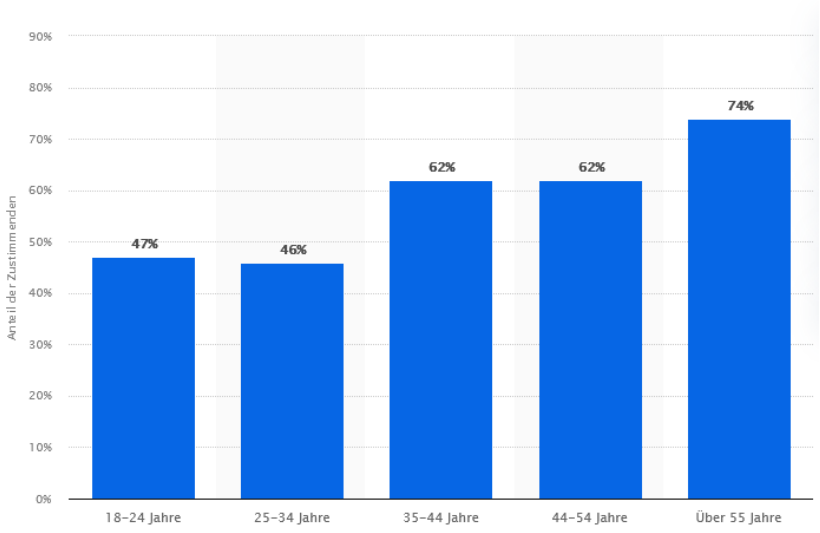

Image 9: Statista (YouGov: Skepsis gegenüber Nachhaltigkeit)

[62] Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit (Greenwashing)
[63] Statista (YouGov: Skepsis gegenüber Nachhaltigkeit)

These figures underscore that detailed, verifiable data on sourcing conditions, production practices, and certification status is no longer optional but expected. Digital traceability systems such as blockchain not only fulfill this expectation but also provide companies with a mechanism to defend themselves against reputational risks linked to greenwashing. This tension between branding and verifiable impact has been particularly visible in the coffee industry. While consumer demand for sustainable and ethically produced coffee continues to rise, many retailers and brands struggle to substantiate their sustainability claims with traceable, audit-ready data. Without transparent mechanisms in place, companies risk not only reputational damage but also legal consequences. The European coffee market, and Germany in particular, represents a high-potential environment for companies that aim to combine ethical sourcing with technological innovation. Businesses that invest in transparent, verifiable, and efficient supply chains not only fulfill their legal obligations but also gain a competitive advantage in terms of brand reputation, investor confidence, and consumer loyalty. Increasingly, both consumers and capital markets demand insights into the social and environmental footprint of the goods they purchase or finance. In this context, supply chain transparency becomes not just a response to compliance pressure, but a strategic asset that signals trustworthiness, reliability, and forward-looking governance. In the absence of such technologies, companies remain vulnerable to accusations of inauthenticity or non-compliance. Pioneer cases are added in the Appendix section (C-F) at the end of this thesis.

Ultimately, the intersection of consumer demand, regulatory expectations, and reputational risk defines the new reality for companies operating in global value chains. The Supply Chain Due Diligence Act serves not only as compliance framework but as catalyst for systemic innovation. For coffee-producing countries in Africa, this transition creates new entry points into verified, ethically governed markets. For European importers, it offers the opportunity to modernize supply chain infrastructure. Greenwashing, in this context, is not merely a risk to be managed, it is a challenge to be met with transparency, accountability, and innovation. Blockchain technology acts as a compliance facilitator by embedding traceability and verification directly into the transaction flow.

5.5 Economic Potential of Fair Trade and Sustainable Coffee in Europe

As shown in both previous chapters, not only Germany, but the whole European coffee market is undergoing a structural transformation. Far from being a regulatory burden,

the shift toward fair and sustainable trade models opens a wide range of economic opportunities for all stakeholders along the coffee value chain. Consumer behavior plays a critical role in this development. Ethically branded coffee products consistently outperform generic offerings in terms of growth rates and customer loyalty. These evolving expectations create an incentive for roasters and importers to invest in verified sustainable sourcing, not just as a reputational safeguard, but as a strategic revenue driver.

A comparative look at Fair-Trade revenue across Europe further underlines the immense potential for ethically sourced products, including Fair-Trade coffee. In 2017, Germany generated about €1.33 billion EUR in Fair-Trade product sales, making it the second-largest market in Europe behind the United Kingdom, which reached €2.01 billion EUR. In 2023 the amount has more than doubled, as shown in the previous chapter. Other countries with significant Fair-Trade activity include Switzerland (€630.58 million EUR), France (€561 million EUR), and Sweden (€394.36 million EUR).[64] When comparing Germany´s Fair-Trade coffee revenue in 2017 (€441.96 million EUR) with 2023 (€837.13 million EUR), the segment grew by over 77% within just six years.[65]

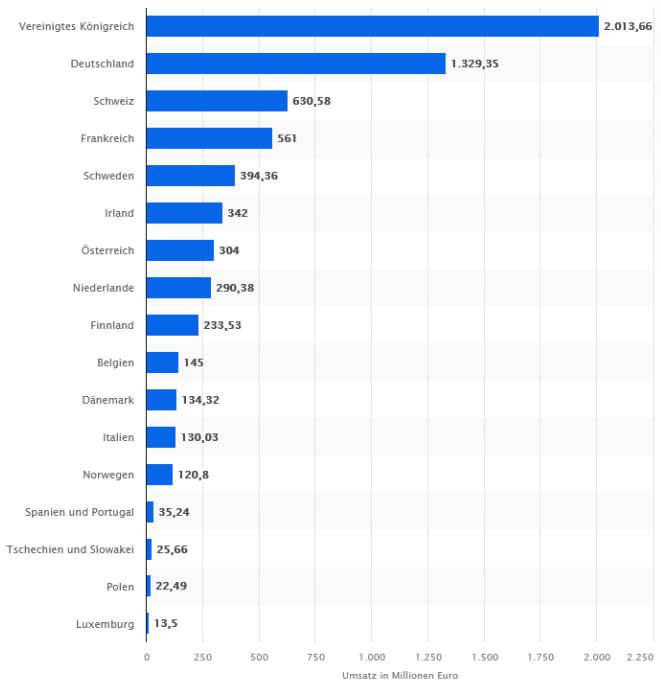

Image 10: Statista (Fairtrade International: Umsatz Fairtrade Europa nach Ländern 2017)

[64] Statista (Fairtrade International: Umsatz Fairtrade Europa nach Ländern 2017)
[65] Statista (TransFair: Umsatz Fairtrade-Kaffee 2011 bis 2024 Deutschland)

If similar growth rates were projected onto other European markets, particularly those with strong consumer awareness and increasing ESG regulation, this could represent a major expansion opportunity for Fair-Trade coffee across the continent.

According to an analysis published by "*Cointelegraph"*, the adoption of blockchain in Western European supply chains could reduce overall costs by up to $450 billion USD annually by minimizing inefficiencies, transaction errors, and administrative burdens.[66] For the coffee sector, this implies not only faster and safer payment flows and better traceability, but also a significant reduction in operational overhead for both importers and exporters. However, despite the projected benefits, blockchain adoption has lagged in recent years. One major factor was the COVID-19 pandemic, which shifted priorities and delayed investment in emerging technologies. As a result, the optimism reflected in such forecasts must be reconsidered against the reality of post-pandemic recovery. The data shows that Europe is not a saturated market, but a dynamic landscape for sustainable products, where transparency, traceability, and ethical sourcing can unlock meaningful economic and social returns.

In parallel, coffee-producing countries in Africa are also positioned to benefit economically from this transition, especially when moving beyond the traditional role of green bean suppliers. Technology is another game-changer, as automation, smart software, and Artificial-Intelligence-driven quality control tools are revolutionizing how coffee is roasted, enabling greater precision, consistency, and scalability. Meanwhile, small-scale and independent roasters are gaining traction by bypassing traditional supply chains, connecting directly with growers, and focusing on authenticity and direct trade. For African coffee farmers, this means closer relationships with roasters and better value retention. Additionally, local coffee consumption across African cities is growing, fueled by a rising coffee culture and a new generation of coffee enthusiasts. This local demand offers producers the chance to move up the value chain by roasting, grinding, and packaging their coffee domestically, strengthening their brand identity and increasing profitability.[67]

From an importer´s perspective, supporting these developments creates dual value: it not only enables legal compliance and brand enhancement in Europe, but also contributes to more stable, high-quality, and resilient supply chains in the long run. Collaborative investments in digital traceability systems, quality infrastructure, and producer training are no longer solely part of corporate social responsibility, they have

[66] Cointelegraph (Study: Blockchain save $450B)
[67] African Fine Coffees Association (Review Magazine Volume 14), pp.6-7

become preconditions for market access and commercial success. Product narratives in combination with transparency and authenticity become monetizable qualities when supported by real evidence and embedded in scalable systems.

In conclusion, the economic potential of Fair-Trade and sustainable coffee in Europe goes well beyond ethical considerations. It represents a fundamental shift in how value is created, communicated, and captured across international supply chains. At the same time, consumer preferences continue to evolve, favoring products with verified impact, authentic origin stories, and measurable sustainability credentials. By investing in ethical sourcing models and long-term supplier relationships, companies can gain competitive advantages in pricing, access to high-quality raw materials, and consumer trust. The ability to clearly differentiate one´s offering through transparency and impact becomes a key lever for brand positioning and market growth. On the production side, coffee-growing regions in Africa are poised to capture a larger share of the final product value by expanding local capabilities, such as roasting, packaging, and quality assurance. These developments, supported by targeted investments and infrastructure, can lead to higher income levels, stronger local entrepreneurship, and greater economic resilience, especially in the face of climate-related challenges and market volatility. In this evolving landscape, sustainable coffee is no longer a niche product category, but a strategic growth area for both producers and importers, which in the end has a positive outcome regarding the revenue part on both ends. Unlocking this potential requires close collaboration, technological innovation, and a shared commitment to equitable value distribution throughout the supply chain.

6. Case Study: Solana and M-Pesa Integration in the Ethiopian Coffee Sector

6.1 African & Ethiopian Coffee Industry - Overview

In January 2025, Africa recorded a 7.1% increase in coffee exports across all types, reaching a total of 1.1 million bags compared to 1.03 million bags in the same month of the previous year. This marks the fourteenth consecutive month of positive export growth for the continent. The January 2025 volume also represents the highest monthly export figure since 1997, when shipments reached 1.12 million bags. With 5.04 million bags exported from October 2024 through January 2025, this coffee year has had the strongest start since the 1992/1993 season, which saw 5.08 million bags exported over the same four-month period. The growth was mainly driven by Côte d´Ivoire and Uganda, which together increased their shipments by 28.1%, from 0.49 million bags

in January 2024 to 0.63 million bags in January 2025, an overall gain of 0.08 million bags. This surge may be partially attributed to reduced export volumes from Vietnam, the world´s largest exporter of Robusta coffee. As leading Robusta exporters within Africa, Côte d´Ivoire and Uganda appear to have compensated for some of the gap left by Vietnam´s decline.[68]

The Asia & Pacific region was the primary contributor to the global decline in coffee exports, experiencing a reduction of 1.62 million bags in January 2025 compared to the same month in 2024. This drop significantly impacted on the region´s overall share of global exports over the twelve-month period ending in January 2025, which fell to 27.1%, a notable decrease from 34.4% recorded during the same timeframe the previous year. This represents the lowest percentage share for the region since February 2011, when it accounted for 26.8%. By comparison, South America currently holds the largest share of global coffee exports at 49.1%, followed by Africa at 12.9%, and the Caribbean, Central America, and Mexico collectively at 27.1%.[69]

Like many African nations, Ethiopia has long faced political unrest, conflict, and socio-economic instability. Its history includes shifts between autocratic regimes and communist military governments, none of which succeeded in driving sustainable economic development. Following the war with Eritrea in 2000, Ethiopia was left burdened with billions of dollars in debt, widespread poverty, and food insecurity.[70] During this period, global coffee prices plummeted below production costs, leaving many farmers unable to maintain their crops due to a lack of financial resources. Ethiopia remains one of the poorest countries in the world, with a significant share of the population depending on low-income. The average daily income in rural areas is estimated at approximately $0.75 USD, which is less than Ethiopians need to cover the costs for their daily life.[71] Despite these challenges, Ethiopian coffee has regained international recognition in recent years, largely due to the deep-rooted cultural attachment of the population to coffee as a traditional heritage product, and a cautious liberalization of the market.[72]

Ethiopia is the largest coffee producer in Africa and ranks sixth worldwide, with an estimated 535.000 hectares dedicated to coffee cultivation. The country produces approximately 435.000 tons annually, equivalent to around 7 million 60-kg bags. The main harvest season takes place between October and January. These production

[68] International Coffee Organization (Coffee Market Report February 2025), p. 8
[69] International Coffee Organization (Coffee Market Report February 2025), p. 7
[70] Happy Coffee (Äthiopischer Kaffee)
[71] Bundeszentrale für politische Bildung (Globalisierung - Äthiopien)
[72] Happy Coffee (Äthiopischer Kaffee)

volumes are primarily generated in highland regions known for their ideal climate conditions for Arabica coffee. The following map illustrates the major coffee-growing areas across Ethiopia, highlighting regional concentrations such as Limu, Sidamo, Jimma, and Yirgacheffe.[73]

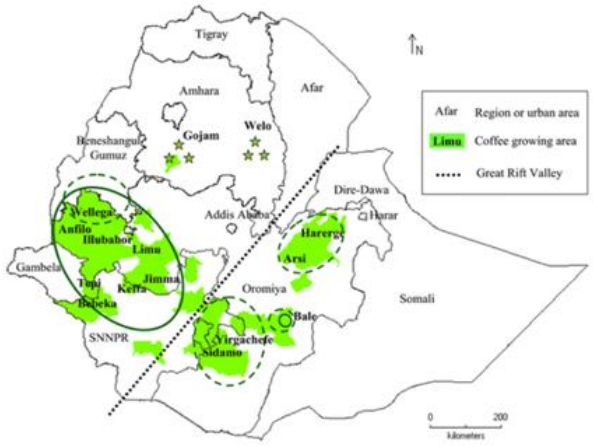

Image 11: Global Agricultural Information Network (Coffee Annual Ethiopia)

The country´s coffee sector is deeply embedded in both its economy and culture, with around 15 million Ethiopians, approximately 25% of the national population, including roughly 5 million smallholder coffee farmers, depending directly or indirectly on coffee for their livelihoods. Climate change significantly threatens Ethiopia´s coffee zones due to increasing temperatures and shifting rainfall patterns. If no adaptive measures are taken, suitable coffee land could shrink drastically by 2050, requiring climate-resilient technologies and forward-looking payment models. This underscores the urgent need to complement technological innovations such as blockchain with climate-resilient agricultural strategies, ensuring both long-term sustainability and income security for vulnerable farming communities in Ethiopia´s highland zones. Production is dominated by smallholder farmers, many of whom use traditional farming methods with minimal fertilizer and pesticide inputs, resulting in relatively low yields of around 400 kg/ha. The majority of these farmers operate on subsistence-level plots with limited access to modern technology. Coffee accounts for nearly one-third of Ethiopia´s total export revenue, yet most of the beans are exported as unroasted green coffee, which limits domestic value creation.[74]

The sector contributes an estimated 30–35% to Ethiopia´s gross domestic product through export revenues, making it a foundation of national economic policy. The

[73] Global Agricultural Information Network (Coffee Annual Ethiopia)
[74] Deutsche Gesellschaft für Internationale Zusammenarbeit (Sektor Brief Äthiopien), pp. 1-3

Government of Ethiopia has therefore prioritized the coffee industry, setting a target of $2 billion USD in export earnings for the 2022/2023 market year.[75]

Ethiopia´s coffee trade is regulated by the Ethiopian Commodity Exchange, which manages quality standards and oversees auctions. While some reforms have allowed cooperatives and larger farms to export directly, over 90% of the crop is still sold through intermediaries. Export revenues are critical for Ethiopia´s foreign exchange reserves, with Germany, the United States of America, Saudi Arabia, and Japan being among the primary importers.[76] Although Ethiopia´s coffee industry is no longer entirely monopolized by the state, it remains heavily regulated. This system means that exporters often have limited control over the precise origin or quality of the beans they purchase, as traceability is restricted by the centralized nature of the supply chain.

Despite the global demand for Ethiopian Arabica and its cultural and economic relevance, the revenue captured at the production level remains minimal. Farmers receive approximately $1.59 USD (€1.40) per kilogram of green coffee (2021).[77] The same coffee is sold at retail in European markets, such as Germany, for around $16.99 – $33.99 USD (€15 - €30 EUR) per kilogram African coffee, which is at least ten times up to 20 times the revenue of a Ethiopian coffee farmer.[78] Estimates suggest that only around 10% of the total profit generated from one kilogram of coffee ultimately ends up in the hands of the farmer.[79]

The Ethiopian coffee sector continues to offer significant growth potential, particularly through productivity improvements such as larger farm sizes, rejuvenation of aging coffee trees, and the introduction of modern agricultural inputs, including irrigation systems and selective use of fertilizers and crop protection. The government has already prioritized these efforts, highlighting the sector´s political relevance. Notably, much of Ethiopia´s coffee is grown organically, yet remains uncertified, presenting a substantial opportunity for value generation.[80]

A critical barrier to achieving this potential remains the dependence on raw coffee exports. Only a fraction of African coffee with less than 1% of revenues is processed domestically, resulting in a lost value creation of billions USD annually. The Ethiopian government has recognized the sector´s potential and prioritized reforms to boost value addition and international competitiveness.[81] Additional challenges persist, especially

[75] Global Agricultural Information Network (Coffee Annual Ethiopia)
[76] Deutsche Gesellschaft für Internationale Zusammenarbeit (Sektor Brief Äthiopien), pp. 2-3
[77] Deutsche Gesellschaft für Internationale Zusammenarbeit (Sektor Brief Äthiopien), p. 2
[78] Idealo (Preisvergleich Afrikanischer Fair-Trade Kaffee)
[79] Bundeszentrale für politische Bildung (Globalisierung - Äthiopien)
[80] Deutsche Gesellschaft für Internationale Zusammenarbeit (Sektor Brief Äthiopien), p. 3
[81] Deutsche Gesellschaft für Internationale Zusammenarbeit (Sektor Brief Äthiopien), pp. 1-2

in marketing and distribution structures, underinvestment in training and equipment, and restricted export rights which limit opportunities for international companies.

6.2 Economic Cost-Benefit Analysis of Blockchain-Based Payment Systems

This section conducts an economic cost-benefit analysis comparing traditional payment systems with blockchain-based alternatives, focusing explicitly on their applicability within Ethiopia´s coffee supply chain. The objective is to quantify the potential economic advantages and identify the initial and ongoing costs associated with implementing blockchain technology in rural agricultural communities. Specifically, this analysis evaluates the financial feasibility, required technological investments, and scalability of blockchain adoption by examining cost factors such as infrastructure requirements, transaction fees, training, technical support, and backend integration. Additionally, the assessment considers broader market dynamics, including rising consumer demand for ethically sourced coffee, global blockchain adoption trends, and price fluctuations due to inflation. Ultimately, the analysis aims to demonstrate whether blockchain-based payment systems present a viable strategy to substantially increase income, enhance market transparency, and sustainably alleviate poverty among Ethiopian coffee farmers, aligning directly with the United Nations Sustainable Development Goal 1 (No Poverty).

The successful integration of a blockchain-based payment infrastructure into Ethiopia´s coffee supply chain requires a range of initial and recurring investments. The primary cost components include mobile device acquisition, mobile internet access, training and onboarding programs, ongoing technical support, and the development of Application Programming Interface (API)-based integrations between blockchain wallets and existing mobile payment systems such as M-Pesa. While the overall technological requirements are relatively modest, the successful rollout depends on both financial feasibility and practical scalability across rural farming communities.

Basic smartphones capable of supporting mobile finance applications represent the first access point to the system. Basic smartphones capable of running mobile finance applications typically cost between $50 and $100 USD.[82] The average price for a 1 GB weekly mobile data package in Ethiopia is around 59 Birr, amounting to 236 Birr a month, which is around $1.81 USD.[83]

[82] Jiji Ethiopia (Mobile Phones)
[83] Ethio Telecom (Mobile Data package)

To ensure system usability, farmers need to be trained in mobile money usage, blockchain transaction flows, and wallet operations. One-time training and onboarding expenses to educate farmers on using mobile money and blockchain technology are necessary. It is not possible to name a specific price range, due to the dependence on the unknown field situation in Ethiopia. To ensure ongoing usability, basic technical support must be considered as maintenance costs but compared to the other cost factors this is relatively high. Therefore, one solution may involve developing Artificial Intelligence (AI)-based assistance tools, such as automated chatbots, interactive knowledge bases, and decentralized ticketing systems to reduce the burden of human intervention. Alternatively, if local capacity allows, parts of the support architecture could be outsourced to regional tech hubs or Non-Governmental Organizations (NGOs), offering employment and ensuring context-specific assistance while reducing dependency on foreign service providers.

Another essential element is the backend development of an integration between M-Pesa and the blockchain wallet. This one-time investment involves the design and deployment of secure API interfaces capable of handling payment processing, token issuance, and user verification.

Depending on the complexity, development costs can surpass $10.000 USD quite fast. A comparable example therefore would be the SAP Green Token, which is priced at around $10.441 USD (€9.216 EUR) and explained in detail in the Appendix F.[84] This price is only for the software integration provided and focuses mainly on European importers as customers. Nevertheless, this cost factor must be considered when planning a wider integration among the majority of Ethiopian farmers. Farmers will also need to connect their wallets individually, with potential fees for onboarding, identity verification, and branded sender names via mobile payment networks. Existing solutions are shown in the Appendix and can be used as a blueprint, or those providers could be approached directly to help implement their blockchain-based solutions. No cost structure is publicly accessible, as the price depends on the offer of the service provider, depending on the specific use case and size of the implementation. Compared to all amounting costs, this upfront cost claims to be the biggest part.

Blockchain systems eliminate the need for multiple intermediaries completely, reducing transaction costs and fees, and preserving a greater share of income for the producers. The Ethiopian coffee farmers oversee their own payment procedure from

[84] SAP Germany Products (SAP Green Token Pricing)

harvesting to transportation and possibly save 5-10% fees per batch of coffee which is handled by intermediaries.

In financial terms, the total cost for a farmer to participate in the blockchain-based payment system is relatively low when compared to the substantial operational benefits. By adopting blockchain-enabled payment flows, farmers can bypass conventional payment cycles that traditionally delay settlement by 30 to 60 days and can instead access immediate payouts in less than five minutes. No additional charges for currency conversion or processing apply, when compared to Swift and Visa systems. Transactional fees are minimal, with blockchain transactions on the Solana network costing approximately $0.00064 USD per transaction, while M-Pesa mobile payment fees range from 1% to 1.5% of the transaction value.

Additionally, the introduction of tokenized reward mechanisms for quality and sustainability performance offers farmers an opportunity to improve their overall earnings by an estimated 10% to 15% through bonuses. These incentives not only reinforce good agricultural practices but also increase farmers´ bargaining power and resilience against market volatility.

The integration of blockchain technology in agricultural supply chains enables coffee farmers to verify the origin, quality, and sustainability of their products in an immutable and transparent way. By linking each batch of coffee to verifiable certifications, such as organic, Fair-Trade, or carbon-neutral farming practices, producers can substantiate premium claims that are increasingly demanded by ethically conscious consumers and international buyers. This digital traceability allows farmers to negotiate higher prices for certified products, thereby increasing their share of the final market value. Premium certification could elevate farm-gate prices by up to 15%–30%, depending on the type of certification and market conditions.

In 2022/23, Ethiopia exported 240.000 tons of coffee and generated $1.33 billion USD, with an average export price of $5.54 USD/kg. While volume fell due to global price pressure and local market diversion, unit prices increased by 16.8%, partly offsetting the revenue decline. The current fiscal goal for 2023/24 is 350.000 tons and $1.75 billion USD in revenue, which appears attainable based on current export performance. A key reason is the expansion of washed coffee processing, which now accounts for 50% of production and commands significantly higher export prices.[85]

All following € EUR amounts have been converted to $ USD for consistency.

[85] STiR Coffee and Tea Magazine (Ethiopia´s Coffee Export)

Moderate calculation approach:

Step 1: Current annual income per farmer

Annual average yield per farmer/farm = 400 kg/ha

Price per exported coffee per kg: $5.54 USD/kg

Farmers share per kg coffee = $1.59 USD (€1.40)

→ Annual income per farm/farmer: 400 kg × $1.59 USD = $634,62 USD

Annual average income in Ethiopia per year: $0,85 × 365 = $310,23 USD

→ coffee farmer earnings are already above double the average income of an Ethiopian

Step 2: Current annual income from total coffee export of Ethiopia

Annual average yield Ethiopia = 435.000 tons = 435.000.000 kg

around 50% exported: 435.000.000 kg × 50% = 217.500.000 kg export

Revenue total at farmers´ level: 217.500.000 kg × $1.59 USD = $345.074.625 USD

→ relatively low compared to $1.33 billion USD in 2022/2023 export year

1% of harvested coffee is processed domestically: 435.000.000 kg × 1% = 4.350.000kg

→ higher prices for exported coffee in general due to processed coffee beans

Step 3: Adjusted price per kg through blockchain integration and technological improvements

Assumptions based on the selling price per kg on the European market:

+25% revenue gain by eliminating intermediaries

+25% premium through certified traceability (Fair-Trade, organic)

+30% kg/ha production due to technological improvements

excluded in the calculation: potential +50% to +100% per kg due to processing the coffee beans domestically

New production volume: 400kg/ha × 130% = 520kg/ha → 565.500 tons = 565.500.000 kg → 282.750.000 kg export

Adjusted price multiplier:1 + 0.25 + 0.25 = 1.50

New price per exported coffee per kg: $1.59 USD × 1.50 = $2.38 USD

→ 50% export price per kg coffee increase at farmers´ level

Step 4: Loss of revenue due to inefficient trade structures

Value gap per kg coffee: $5.54/kg - $1.59 = $3.95 USD

400kg × $3.95 = $1.580 USD per farmer per year

→ 2.5 × times loss of revenue compared to actual earnings of farmers

→ reasons therefore could be additional intermediaries, corruption, based on a mostly cash-based system, or taxes, which are not included in the calculation at all

Step 5: New annual income per farmer

New income with 520 kg/ha and blockchain implementation: 520 kg × $2.38 USD = $1.238 USD

→ nearly 50% increase at farmers level income per kg coffee ($634,62 USD)

→ 4 × times the annual average income of an Ethiopian per year

Transaction execution costs:

Assumption: transactions are executed via M-Pesa or traditional banking systems for international remittances, cash payments are equivalent and paid directly to intermediaries, who then sell the coffee abroad

→ $0.00064 USD per transaction on the Solana Blockchain

→ M-Pesa mobile payment fees range from 1% to 1.5% of the transaction value

→ Visa or Swift transactions: minimum fee per transaction of $8.95 USD (€7.90 EUR), around 5% + 2.5–3% additional conversion rates

Example calculation for one farm/farmer:

Assumptions:

- four transactions per month, one per week during harvesting season (16 total transactions per farm/farmer)

  → 1. Solana: $0.00064 USD 16 = $0.01024 USD (just above one cent for all transactions in the whole harvesting season!)

  → 2. M-Pesa: $634.62 USD/16 × 1,5% = 39.66 × 1,5% = $0.60 USD per transaction, $9.60 USD per harvesting season

  → 3. Visa/Swift: if a bank account exists, minimum transaction fee: $8.95 USD + $1.20 USD per transaction (3%) = $10.15 USD per transaction

  $10.15 USD × 16 = $162.4 USD per harvesting season

  $162.4 USD / $634.62 USD ≈ 26%

  → ≈ 26% of farmers revenue would be for transaction costs only

Due to the reason of the low-income level and earnings at the farmers level below the poverty rate, those considered small amounts can make a big difference. Scalability becomes an important factor regarding further calculation. The more transactions and the higher the amount per transaction, the more fees have to be paid via M-Pesa and

Swift/Visa. The calculation even exceeds, when transferring the transaction costs from one farmer to all the farmers in the Ethiopian coffee production sector.
Important: This calculation approach only covers the sale of coffee beans and no transactions regarding fertilizer or working tools. Those transactions can theoretically also be processed via the blockchain and therefore serve as an additional cost-saving factor.

Additional price-boosting scalability factors:

1. Demand for transparency of ethical sourced coffee (see chapters 5.4 and 5.5)
2. Blockchain technology growth (see chapter 3.1)
3. Inflation rate of Ethiopian Birr: 21.5%

Given Ethiopia´s high inflation rate, averaging approximately 21.8% in 2024 and projected to remain elevated at around 21.5% in 2025, implementing traditional currency-based payment methods poses substantial financial risks to farmers due to significant purchasing power erosion. Between 2025 and 2030, although forecasts predict a gradual decrease of approximately 9.3% in Ethiopia´s inflation rate, monetary instability will remain a critical economic challenge.[86]

Breakdown of implementation costs:

Step 1: Smartphone mobile devices and data plan:

Devices need to have internet and wallet access, possibly M-Pesa capability
→ $50 to $100 USD per device (75$ USD average for calculation)
Assumption: 20% of farmers need a device (due to the number of individual farmers)
1 million farmers × $75 = $75 million USD to provide all farmers with use case related capability smartphones
Data plans per month (only harvesting season)
→ $1.81 × 4 = $7.24 USD per farmer (in total: $7.24 million USD)

Step 2: Onboarding costs per farm/farmer

→ not precisely calculable (estimated $10–$25 USD per farmer), possibly higher costs when onboarding has to be done on site directly
→ recommendation: Group onboarding sessions via NGOs/local partners

[86] Statista (Inflationsrate Äthiopien)

Step 3: Ongoing technical support

Assumption: only necessary during harvesting season (October-January, 4 months)

→ n.a. due to out-of-scope field research in Ethiopia, estimated to be more relevant in the beginning, maybe assistance of European importers needed (high costs expected due to higher base income levels)

→ recommendation: support provided through NGOs or local partners (if possible), scaling solutions with AI or Bots (efficient cost reduction and low level of maintenance)

Step 4: Development costs for API connection

SAP Software solution "Green Token": $10.441 USD (€9.216 EUR), only the cost of the software and more a solution for the importer, tokenization principle can be used and transferred to the farmers.

API integration:[87]

1. Small Business API Integration ($2,000 – $5,000 USD): Includes basic functions such as secure payment gateways (e.g., Stripe) and automated shipping solutions, characterized by simplicity, ease of implementation, and low cost due to widely available documentation.
2. Custom SaaS Platform API Integration ($10,000 – $25,000 USD): Covers tailored functionalities such as secure user authentication, sophisticated data processing, and analytics, providing a scalable, secure, and efficient long-term infrastructure for moderate complexity scenarios.
3. Enterprise-Level API Integration ($50,000 + USD): Involves advanced real-time data processing, robust security frameworks, and AI-powered functions, suitable for complex high-volume transactions and stringent compliance environments, reflecting significantly higher costs due to extensive infrastructure demands.

Given the context of integrating blockchain-based payments via M-Pesa with tokenization and stablecoin functionalities, the Custom SaaS Platform API Integration ($10,000–$25,000 USD) is most appropriate. It effectively balances scalability, security, and sophisticated feature requirements necessary to manage secure transactions, token issuance, identity verification, and interoperability between blockchain wallets and existing mobile payment systems, while maintaining

[87] Planeks (API Cost Calculator)

reasonable implementation costs and ensuring sustainable operations for Ethiopian coffee producers.

The cost-benefit model confirms that a pure, on-chain Solana payment rail, leveraging tokenization and USD-pegged stable-coins almost double farm-gate income once efficiency gains (+25%), traceability premiums (+25%) and modest improvements (+30%) are realized. Average revenue rises from $635 USD to $1.238 USD per farmer, lifting the daily earning potential to ≈ $3.39 USD, comfortably above the World-Bank extreme-poverty line of $2.15 USD. Such effect would appear for all related parties in the coffee industry sector, meaning over 30 million Ethiopians (25% of > 130.000.000) would benefit directly. The whole country, Ethiopian GDP and wider seen the African continent would benefit indirectly from such development. Transaction economics further reinforces the argument. The harvest season settled on Solana costs ≈ $0.01 USD in network fees, versus $9.60 USD on M-Pesa and ≥ $162,4 USD through Swift rails. Because a direct blockchain pathway avoids the bespoke API bridge, KYC duplication, and maintenance stack required to couple M-Pesa with crypto wallets, upfront integration expenditure falls by at least $10.000–25.000 USD at project level, and unit onboarding costs decline correspondingly. In addition, dollar-denominated stable-coins insulate growers from Ethiopia´s double-digit inflation (≈ 21%), a macro-risk that erodes any Birr-based payment routed through mobile money. Taken together, these findings show that a stand-alone blockchain solution is not merely technically viable but economically superior, delivering rapid pay-back on modest hardware and training outlays while generating permanent, poverty-reducing income uplifts. Hence, for stakeholders committed to SDG 1 (No Poverty) and long-term sector resilience, the strategic recommendation is unequivocal: deploy an end-to-end Solana payment architecture and bypass intermediary mobile-money layers altogether.

6.3 Technical Implementation Framework

6.3.1 Smart Contract Architecture

The implementation of a blockchain-based payment infrastructure for Ethiopian coffee farmers relies heavily on a well-designed smart contract architecture capable of automating and securing payment processes. On the Solana blockchain, smart contracts, referred to as “programs” are typically developed using the Rust programming language or the Anchor framework, which abstracts many of the lower-level complexities of Rust and simplifies development workflows. These contracts can be programmed to manage conditional payments, store delivery data, and interact with

custom tokens (e.g. Coffee Token) or stablecoins (e.g. USDC and USDT) based on predefined triggers such as shipment confirmation or verified quality inspection.

A smart contract on Solana designed for this use case would follow a modular structure. The first module would handle delivery verification, ensuring that a specific batch of coffee has been successfully delivered by the farmer to a registered cooperative or washing station. This verification process would be conducted through QR code scanning, whereby each delivery is linked to a unique batch identification (ID) encoded in a scannable code. Upon delivery, an authorized cooperative staff member scans the QR code using a mobile device connected to the blockchain interface, which then triggers the verification event on-chain. Once this verification is completed, a second module of the smart contract would automatically execute the payment logic, transferring a predefined amount of USDC to the farmer´s wallet address (whether crypto or M-Pesa wallet). To ensure usability for smallholder farmers with limited digital literacy, the recipient wallet would be a custodial mobile wallet integrated with M-Pesa, managed through an off-ramp service provider. This ensures that the payment is received directly as local fiat currency in the farmer´s mobile money account, requiring no interaction with traditional crypto wallets or exchanges.

The connection between the Solana blockchain and the M-Pesa mobile money network is made possible using off-ramp API service providers, such as Moonpay. These intermediaries serve as vital infrastructure in bridging on-chain stablecoin payments with local fiat currency payouts, ensuring seamless integration between decentralized financial systems and established mobile payment platforms in Africa. When the smart contract on Solana is triggered, typically following verified delivery of a coffee batch which the off-ramp provider automatically receives the transaction details via API. Upon receipt of the event, the provider converts the stablecoin value into local currency, in this case the Ethiopian Birr, using liquidity pools or pre-established treasury reserves. The equivalent fiat amount is then transferred directly to the farmer´s M-Pesa mobile wallet, completing the payment cycle. The entire process occurs in near real-time and is fully automated, reducing the need for human intervention or traditional banking procedures. This integration not only guarantees speed and reliability but also ensures that the farmer receives their payment in a familiar and accessible format, using the same M-Pesa application already widely adopted across East Africa. Most importantly, it eliminates the need for farmers to interact with crypto exchanges, manage private keys, or understand blockchain mechanics, lowering the barrier to entry and ensuring the model is inclusive for rural populations with limited digital literacy. By leveraging the technological strengths of both systems, Solana´s

scalability and M-Pesa´s widespread accessibility over Africa, this off-ramp architecture enables a farmer-friendly blockchain payment system that directly supports fair compensation mechanisms.

The successful implementation of this Solana-based blockchain payment system depends on a set of key technical and infrastructural prerequisites to ensure accessibility, reliability, and scalability in real-world supply chain environments. Firstly, there must be a secure and well-maintained local registry that maps each farmer´s identity and M-Pesa number to a corresponding Solana-compatible custodial wallet address, managed by the off-ramp service provider. This mapping is essential but considered very complex, for enabling smart contracts to correctly identify recipients and direct payments without manual errors or fraud. The registration process can be coordinated through local cooperatives or agricultural unions and may require initial identity verification, possibly supported by biometric or national ID systems where available to prevent fraud in the first place. Secondly, coffee cooperatives, washing stations, and warehouse facilities must be equipped with basic digital tools, such as smartphones, tablets, or QR-code scanners. To ensure integrity, these devices must be connected to the internet and synchronized with the blockchain interface, either through a mobile decentralized application or a lightweight transaction portal maintained by the project operator. Thirdly, the entire system must be supported by a user-friendly interface that allows all stakeholders, including farmers, cooperative managers, and logistics partners, to interact with the blockchain infrastructure without requiring blockchain-specific knowledge. Such tools would allow users to check payment status, confirm delivery receipts, or resolve discrepancies in real time. To build trust and increase adoption, training sessions and technical support must also be provided at the community level, ensuring that all actors can navigate the platform confidently.

In terms of complexity, the technical implementation is moderate to high, requiring coordination between blockchain developers, local supply chain actors, and financial service providers. However, once deployed, the architecture is designed to be self-sustaining and automated, drastically reducing manual intervention, risk of fraud, and processing time. It also creates an immutable audit trail of all transactions and deliveries, which is valuable not only for internal tracking but also for fulfilling the legal requirements. Ultimately, the smart contract system represents the foundation of the proposed fair compensation model. It bridges international buyers and local producers, ensures enforcement of payment agreements, and builds a decentralized but highly functional infrastructure for inclusive agricultural finance. This structure will

serve as the technical foundation for token-based transactions discussed further in the following chapter 6.3.2.

6.3.2 Automating Payments and fair Compensation through Tokenization

To further streamline and standardize blockchain-based payments in agricultural supply chains, tokenization presents itself as a powerful tool, especially when applied to sectors like coffee production. In simple terms, tokenization refers to the process of converting the value of a real-world asset or action (such as the delivery of a coffee batch) into a digital representation on the blockchain. These digital units, known as tokens, can be programmed, transferred, and tracked in real time within a decentralized network.

In the context of this thesis, tokenization enables the automation of payment and compensation systems by eliminating manual processing steps, the setting up of an API connection and providing a transparent, verifiable trail of who delivered what, when, and how much they are owed. Rather than issuing a direct stablecoin payment upon delivery, a smart contract can first generate a token that represents the delivered product or the value thereof, which can then be exchanged or redeemed for actual payment in stablecoins directly on the Solana blockchain. This additional layer of abstraction offers several benefits.

First, it allows for standardized valuation of coffee deliveries, as each token can be assigned a fixed or dynamic value depending on pre-defined delivery conditions such as weight, quality, or origin. Second, it introduces greater flexibility and auditability: tokens can be used not only for instant payouts but also to track cumulative deliveries, verify eligibility for premiums (e.g. for certified organic or high-quality coffee), or even build decentralized farmer reputations based on performance data stored immutably on-chain. Thus, tokenization forms the basis for an advanced compensation architecture that is more transparent, programmable, and scalable than conventional direct-payment models. It supports both technical efficiency and compliance with regulations such as the German Supply Chain Due Diligence Act, by ensuring that each transaction is not only recorded, but also represented and managed in a structured, tamper-proof, and verifiable manner.

In the proposed architecture, the Coffee Token (imaginary) serves as a digital representation of a coffee delivery made by a farmer to a registered cooperative or washing station. It is a fungible Solana Program Library (SPL) token built on the Solana blockchain. Each Coffee Token is directly linked to a verified delivery and is

minted, which means being created by a smart contract once a delivery is confirmed through QR-code scanning and approved by the cooperative staff. The token itself functions as a digital receipt with monetary value, ensuring traceability, accountability, and future payment eligibility.

After a batch of coffee has been scanned and validated, the smart contract initiates a "minting" function that issues Coffee Tokens to a pre-defined wallet address. The number of tokens issued corresponds to the delivery volume and quality parameters set by the cooperative or importing buyer. The Coffee Token is not just a symbolic unit but a programmable utility token, meaning it can carry embedded rules and permissions. For example, tokens can be time-locked to prevent immediate conversion, contain metadata about the origin and sustainability certifications of the delivery, or be used to trigger bonuses for exceeding certain delivery thresholds. They can also serve as a record to calculate total earnings over a harvest season, support Fair-Trade reporting, or power a reputation system where farmers earn higher ratings based on consistent and high-quality deliveries. By introducing the Coffee Token, the payment process becomes both verifiable and programmable, while maintaining flexibility in how and when value is distributed. It also creates opportunities for data analysis and future integrations, such as enabling access to microcredit, offering reward systems for sustainable farming practices, or supporting blockchain-based traceability for European importers.

The following process model illustrates how an Ethiopian coffee farmer is compensated via blockchain directly and via the off-ramp connection with M-Pesa from the moment of harvesting the coffee beans, while the end consumer in a European retail environment can later verify the product's origin through transparent, on-chain traceability. Mind the notes regarding the steps 4 – coffee token conversion and 8 – payment, which are only applicable in the tokenization process, which is the recommended one. Step 5 covers the off-ramp connection with the farmer´s M-Pesa account.

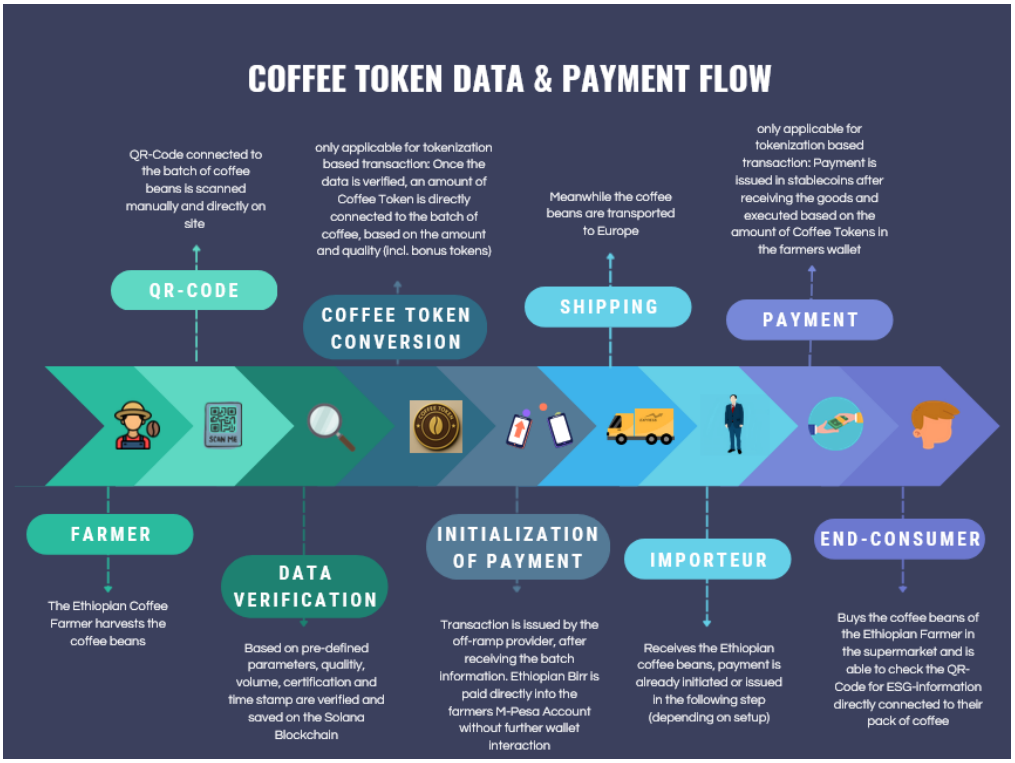

Image 12: Coffee Token Data & Payment Flow, own illustration

Once the farmer delivers a batch of coffee to a certified cooperative or processing station, the product is weighed and linked to a unique batch QR-code. A cooperative staff member scans this QR-code via a dedicated mobile application connected to the Solana blockchain backend. The scan triggers a smart contract function, which verifies the batch against internal records (e.g., farmer ID, delivery quota, quality grade) and logs the delivery event immutably on-chain. Once verified, the smart contract calculates the corresponding token value or corresponding stablecoin value based on predefined parameters, typically the volume and quality of the coffee. Predefined standards and valuations of Coffee Token and coffee volume or quality are essential but can be set flexible. For example, one kilogram of standard-grade coffee may equal 1 Coffee Token, while premium-grade deliveries may be weighed higher, issuing 1.25 tokens per kilogram. 1 Coffee Token may equal a certain amount of stablecoin value. In cases where the delivery meets additional sustainability criteria, such as certified organic status, Fair-Trade compliance, or agroforestry integration, the farmer receives an automated bonus in the form of extra Coffee Tokens. This bonus function is embedded directly into the smart contract logic and is activated upon submission of the appropriate certification data. These additional tokens serve as both financial incentives and documentation tools for sustainability performance, reinforcing compliance with European supply chain laws.

Following token issuance, the payment process is initiated by the importer or platform provider based on the shipping confirmation and batch metadata. In the “Initialization

of Payment" stage, the off-ramp provider converts the stablecoin into local currency, Ethiopian Birr and transfers the money directly into the farmer´s M-Pesa account. Regarding a tokenization-based transaction process, in the "Payment" phase, the transaction is executed based on the corresponding Coffee Token value via stablecoins into the farmer´s blockchain wallet. Meanwhile, the coffee beans are being transported to Europe and can soon be bought and traced back to the origin by the customers.

6.3.3 Ensuring Price Stability in Blockchain Payments

Volatility remains one of the most significant barriers to the widespread adoption of blockchain-based payment systems. Cryptocurrencies like Ethereum or Solana, while decentralized and efficient in terms of transaction speed, are highly prone to price fluctuations. A payment agreed upon in the morning might lose a substantial portion of its value by the time it is received, especially in volatile markets. For smallholder coffee farmers, who often operate on narrow financial margins, such unpredictability could mean the difference between breaking even and falling into debt. This makes price stability a non-negotiable requirement when considering blockchain as a viable infrastructure for agricultural payment systems. Fast changing valuation gaps are demonstrating why price stability is an important factor in combination with blockchain technology payment systems. Non reliant systems are not suitable for the case analyzed within the thesis. To address this problem, stablecoins have emerged as a promising solution. Unlike traditional cryptocurrencies, stablecoins are designed to maintain a stable value by pegging their worth to real-world assets, such as fiat currencies. The two most widely used examples are USD Coin (USDC) and Tether (USDT), both of which are pegged 1:1 to the U.S. dollar.

The underlying structure of stablecoins varies depending on their collateralization model. Fiat-collateralized stablecoins such as USDC and USDT are backed by reserves held in real-world assets, mainly U.S. dollars or equivalent short-term securities. Tether, which is the most widely used stablecoin in the world by market capitalization, claims to be fully backed by a mix of cash, commercial paper, corporate bonds, and other assets, though it has faced criticism in the past regarding the transparency of its reserves.[88]

In practice, stablecoins work by enabling users to mint or redeem tokens based on fiat deposits. When a user deposits $100 USD, for example, they can receive 100 USDT in return, which can then be transferred or stored on the blockchain. Conversely, users can return 100 USDT and receive the equivalent amount in fiat. This peg mechanism

[88] Tether (Why Tether)

is maintained through the reserve system and, in some cases, algorithmic adjustments or market arbitrage incentives. Since the value of the stablecoin remains tied to a stable asset, users are protected from the extreme volatility seen in non-pegged cryptocurrencies. By integrating stablecoins into blockchain payment systems for agricultural producers, a new level of security and predictability can be achieved. For coffee farmers, receiving compensation in stablecoins ensures they can trust the purchasing power of their income, regardless of fluctuations in the crypto markets. Furthermore, since transactions are executed through smart contracts, payment execution can be automated and verifiable, reducing the likelihood of human error or delayed disbursements. Additionally, stablecoins can be used a security against inflation of local currency.

In the context of Solana-based blockchain systems, both USDC and USDT are already supported, allowing for fast and cost-efficient transactions without compromising price stability. As stablecoins become more regulated and widely adopted, they are likely to play a foundational role in the future of global financial inclusion.

Another option, directly related to the Coffee Token and for stabilization would be in terms of issuance and supply, that Coffee Tokens can be minted on-demand by the smart contract and “burned” (= removed from circulation) after they are redeemed for payment. This ensures that the token system remains balanced and inflation-proof, reflecting actual economic activity rather than speculative trading. It is important to note that Coffee Tokens are not designed to be volatile cryptocurrencies, but rather fixed-value instruments with 1:1 backing to a stablecoin unit or fiat equivalent, thus ensuring price transparency and simplicity for the farmer.

In assessing the long-term economic viability of blockchain-based payments, this thesis identifies two practical payout models: direct stablecoin wallets and an integrated M-Pesa bridge. Direct stablecoin wallets offer the most inflation-resilient and cost-effective solution in the long term, minimizing transaction fees and preserving purchasing power through USD- or EUR-pegged assets. The M-Pesa method leverages off-ramp providers like Moonpay to convert stablecoin balances into Ethiopian Birr and deliver them via mobile money, eliminating the need for direct interaction with blockchain wallets and connection to local currency. In contrast, stablecoin wallets support full decentralization and financial autonomy, enabling farmers to benefit from broader DeFi services. A detailed comparison of the two blockchain-based payout models, M-Pesa offramp integration and direct stablecoin wallet usage can be found in Appendix B.

To provide a structured, business-oriented perspective on the implementation of blockchain-based payment models in Ethiopia´s coffee supply chain, a Balanced Scorecard framework has been developed. This strategic management tool synthesizes the key findings of the case study and the economic analysis by evaluating five perspectives: Learning & Innovation, Financial, Customer & Market, Sustainability & ESG, and External & Regulatory. Each dimension defines specific objectives, key performance indicators (KPIs), and measurable targets that reflect the potential of blockchain technology to enhance income, resilience, and traceability while addressing macroeconomic risks such as inflation and regulatory challenges. This Scorecard serves as a guiding instrument for assessing long-term viability, operational priorities, and stakeholder value creation.

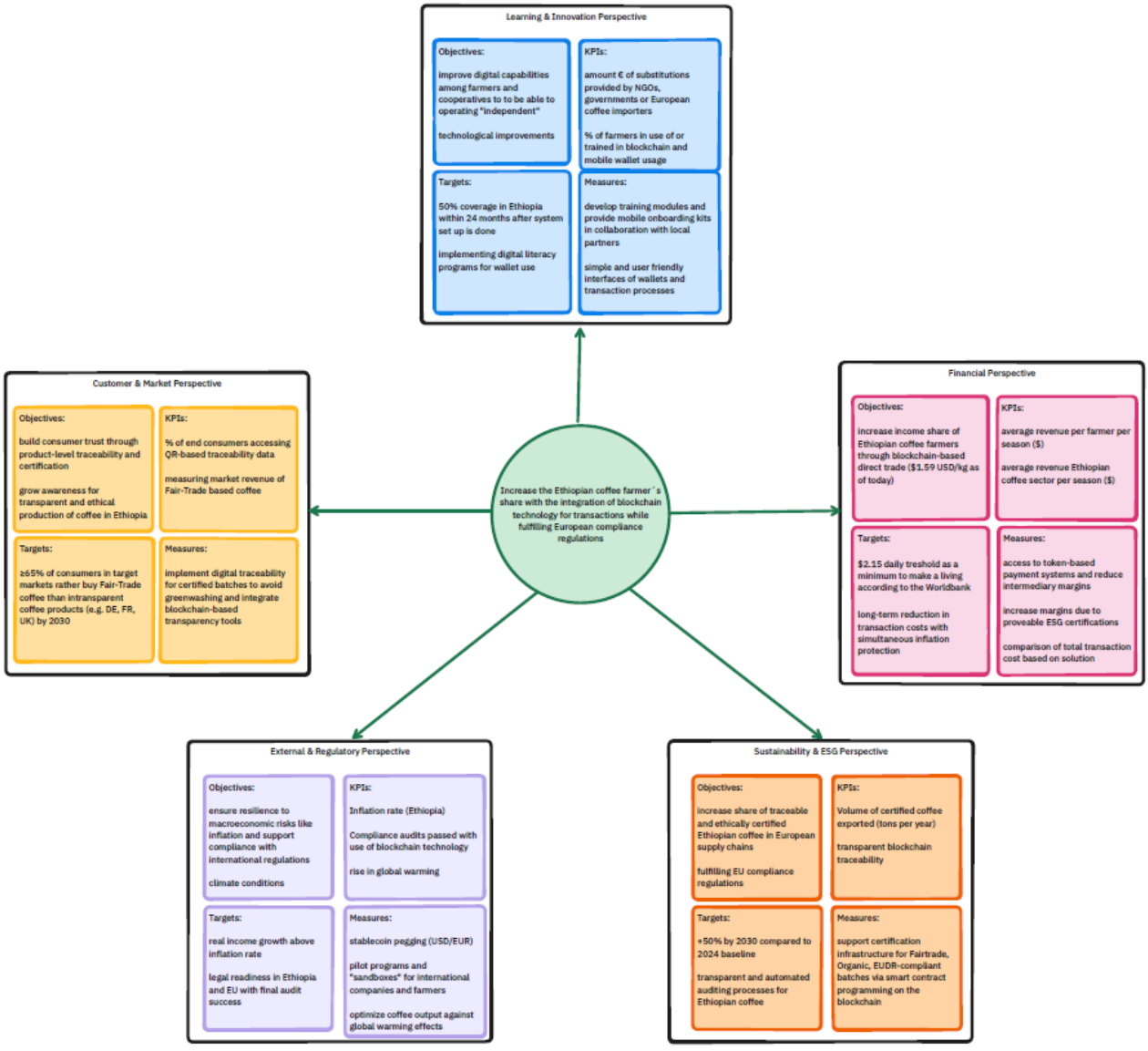

Image 13: Balanced Scorecard, own illustration

7. Barriers to Adoption and Mitigation Strategies

7.1 Legal and Infrastructural Challenges

Regulatory uncertainty represents a critical barrier to the widespread implementation of blockchain systems in global agricultural trade. Legal ambiguities regarding smart contract enforceability, cross-border data governance, and liability in case of transactional errors create risk for both importers and producers. Key legal questions remain unanswered: Are smart contracts legally binding in cross-border trade? Which jurisdiction applies in case of disputes? Who bears liability in the event of errors or fraudulent transactions? And how does blockchain-based data storage align with international data protection laws such as the General Data Protection Regulation? How should taxes be handled in the trade included countries? Without harmonized legal frameworks, the potential benefits of real-time auditability and decentralized verification may be undermined by institutional hesitation and compliance concerns. To mitigate this, structured public-private partnerships and regulatory sandboxes can provide test environments with temporary legal clarity, while educational programs on digital contracts can strengthen understanding among cooperatives. At the same time, a lack of access to essential hardware, such as smartphones or other internet-enabled devices, further hinders participation. To overcome this obstacle, European importers must be prepared to co-finance or directly supply hardware infrastructure as part of a long-term partnership strategy. This may include bundled programs involving device leasing, donation schemes, or public-private partnerships that ensure the technical entry threshold is not a barrier to financial inclusion.

Public-private partnerships are increasingly proving essential for developing blockchain infrastructure in emerging economies. As outlined in the GBBC Annual Report, countries like El Salvador, Colombia, and Bolivia have launched national blockchain initiatives through such partnerships, combining public sector coordination with private sector innovation and technical expertise.[89] These examples illustrate how public-private partnerships can accelerate access to digital finance and scalable infrastructure, offering valuable reference points for Ethiopia´s own blockchain ambitions. Such models reduce the entry barrier for technology adoption and spread both the operational load and investment risk across multiple actors. Providing this type of foundational support would not only facilitate system usage but also demonstrate commitment to fair and inclusive trade practices beyond contractual

[89] Global Blockchain Business Council (GBBC Annual Report 2024), p.59

obligations. Finally, establishing decentralized tech hubs at key points in the supply chain can serve as anchor institutions for onboarding, verification, and compliance, ensuring that blockchain integration is not only technically feasible but institutionally embedded. It is essential to emphasize that, from a purely technological standpoint, blockchain-based payments do not require such hubs in order to function. Transactions can theoretically be initiated and validated via mobile wallets or individual nodes connected to the blockchain network, where basic internet access is provided.

7.2 Structural and Educational Barriers

The implementation of blockchain-based payment infrastructures in the Ethiopian coffee sector faces a range of interrelated structural and educational barriers. Thus, the rollout of a Solana-based payment solution cannot be a top-down technological imposition but must instead be accompanied by strategic and sustained support programs tailored to the realities of local farming communities. European coffee importers, as the direct beneficiaries of increased transparency and compliance, carry a shared responsibility to empower their upstream partners. A key issue is the limited digital literacy among smallholder farmers, who often lack familiarity with smartphones, internet-based applications, and concepts such as smart contracts or tokenization. Even when mobile money solutions such as M-Pesa are already in use, the additional complexity of blockchain systems presents a significant adoption hurdle. To address this, European importers must take on active responsibility, not only for ensuring compliance-relevant documentation, but also for equipping their upstream partners with the tools, knowledge, and infrastructure needed to interact with the system. Practical interventions include co-financed training programs, multilingual mobile applications with simplified interfaces, and onboarding through cooperatives and local NGOs. Local fintech providers could assist with delivering on-site or mobile-based training sessions that explain how the payment system works, how it benefits the farmer, and how to troubleshoot issues. Importantly, training must be ongoing and seasonally aligned with the agricultural cycle. These efforts are not merely supportive, but strategically necessary for enabling trustworthy, scalable blockchain adoption at the origin. To reduce the technical and administrative burden, one solution lies in outsourcing parts of the blockchain stack through Infrastructure-as-a-Service models. These modular solutions, ideally open-source and hosted regionally, could provide standardized tools like wallets, dashboards or reporting interfaces, without requiring every actor in the supply chain to maintain their own custom setup. Importantly, these

IaaS layers would be designed to adapt to jurisdiction-specific compliance requirements, allowing for easier rollout across multiple countries and regions.

7.3 Environmental and Financial Concerns

A further, often overlooked barrier is the perception of blockchain as environmentally unsustainable, a concern particularly relevant for ethically conscious consumers and sustainability-focused regulators. Misconceptions rooted in high-energy blockchains such as Bitcoin may deter stakeholder buy-in, despite Solana´s proven energy efficiency. This underscores the importance of transparent communication and the use of empirical data to demonstrate the low carbon footprint of modern blockchain solutions. Ultimately, reframing blockchain as an enabler of environmental transparency, rather than an ecological threat, requires deliberate communication and technical clarity. Strategies such as integrating solar-powered infrastructure, publishing third-party energy audits, and incorporating blockchain into ESG reporting can help reframe the technology as a contributor to sustainability rather than a threat. Given the favorable climatic conditions in regions such as southern Ethiopia, small-scale solar installations could sustainably cover the energy demands of transaction processing, effectively eliminating reliance on fossil-based grids. This not only reduces the ecological footprint of blockchain systems but may also help to cover transaction fees over time, especially when surplus energy is reinvested into community-operated digital infrastructure. In doing so, blockchain adoption becomes part of a broader renewable energy narrative, supporting local resilience, cost-efficiency, and environmental credibility. Finally, the economic sustainability of scaling efforts depends on strategic financing models that distribute costs and risks fairly among stakeholders. These systems are well-positioned to receive support from impact-driven capital. Development agencies, such as the German GIZ or the European Investment Bank, could incorporate blockchain infrastructure into their digital development portfolios, particularly when projects are tied to food security, climate resilience, or labor rights. Moreover, ESG-focused investment funds could view blockchain-based trade systems as a new asset class, offering both measurable impact and built-in auditability, two features often lacking in traditional ESG products. To overcome those barriers, a multi-level regulatory strategy is required. On a supranational level, the European Union should accelerate the development and rollout of coherent blockchain frameworks such as Markets in Crypto-Assets Regulation (MiCA), which aim to standardize legal definitions and ensure cross-border compatibility. In parallel, bilateral agreements or development partnerships could

support the establishment of regulatory sandboxes in key African trading hubs. These sandboxes would allow stakeholders to test blockchain applications under controlled conditions, with temporary legal exemptions that encourage experimentation without legal risk. Importantly, investments made within these environments could be classified as exploratory research and development (R&D) expenditures rather than direct commercial deployments. This framing may open access to innovation funding from public or development-oriented sources, given the underexplored nature of blockchain integration in agricultural supply chains and the broader need for digital transformation in the sector.

8. Conclusion and Outlook

8.1 Summary of Key Findings

This thesis has demonstrated that blockchain-based payment systems, when thoughtfully integrated into agricultural supply chains, offer a powerful, scalable, and economically viable mechanism to improve income distribution, ensure regulatory compliance, and strengthen transparency within global value networks. Using Ethiopia´s coffee sector as a case study, it was shown that meaningful systemic change can be achieved with relatively low investment. Basic infrastructure such as affordable smartphones, mobile internet access, and short-cycle digital training enables smallholder farmers to participate in a decentralized system that delivers real-time, traceable, and inflation-resistant payments.

Two distinct payout models were analyzed. The first model routes stablecoin-based payments through off-ramp providers to M-Pesa, enabling farmers to receive funds directly in Ethiopian Birr. While this approach ensures accessibility for digitally underserved communities, it involves higher technical complexity and costs related to the API and off-ramp infrastructure. In contrast, the second model involves direct stablecoin wallet payouts. Although it requires basic digital literacy and initial onboarding, it eliminates intermediary fees, avoids currency conversion losses, and provides farmers with greater financial autonomy and resilience against inflation.

The analysis identified Solana as the most suitable blockchain infrastructure for this use case due to its minimal energy requirements, high scalability, and exceptionally low transaction costs (~$0.00064 USD per transaction). Its energy-efficient proof-of-history consensus addresses environmental concerns often associated with blockchain

technologies, offering a climate-friendly solution particularly relevant for coffee regions in Ethiopia that are already vulnerable to climate change.

From the farmer´s perspective, the benefits are tangible: faster payments, reduced costs, protection from currency devaluation, and access to formal digital financial systems, creating a bigger share of the coffee sold. These outcomes are no longer theoretical but operationally feasible. Simulations showed that annual income could increase from $634,62 USD to approximately $1.238 USD per farmer, exceeding the World Bank´s extreme poverty threshold of $2.15 USD/day by more than $1.24 USD. This underscores the potential of blockchain to contribute directly to around 25% of the population in relation to SDG 1 (No Poverty).

On a macroeconomic level, the export revenue of Ethiopia´s coffee sector could increase by over €2 billion EUR annually, based on a 50% export share at improved prices. This projection remains conservative, as it does not account for further multipliers such as growing global demand for traceable products, rising coffee prices, technological productivity gains, or the ongoing expansion of the blockchain sector. Additionally, tokenized traceability aligns seamlessly with international due diligence regulations and allows importers to fulfill ESG reporting requirements.

Another key insight is the system´s modularity and transferability: while this thesis focuses on Solana and M-Pesa in Ethiopia, the architecture is not limited to one geography or platform. It is compatible with other payment networks (e.g., Flutterwave, PayPal) and can be adapted to different agricultural value chains across Sub-Saharan Africa, Latin America, and Southeast Asia. This makes it not only a pilot model, but a globally scalable framework for inclusive digital trade.

Finally, blockchain-based traceability and payment systems emerge from this study not as futuristic speculation, but as implementable, climate-smart, and socially impactful technologies. They resolve structural inefficiencies in current trade systems while laying the foundation for a digitally sovereign, transparent, and equitable agricultural economy. The result is a virtuous cycle: broader inclusion enables new investment, investment fosters infrastructure and productivity, and increased competitiveness drives long-term sustainability. Ethiopia, and Africa more broadly, can lead this transformation not by copying industrial models, but by defining new standards for ethical, efficient, and decentralized trade.

8.2 Future Research Directions

While this thesis has outlined the multifaceted benefits of blockchain integration in the African coffee trade, ranging from fairer economic structures to enhanced

environmental transparency, based on a profound cost-benefit case study, it also reveals the limitations and open questions that remain. As blockchain technology continues to evolve rapidly, several promising directions emerge for future research, particularly in the context of sustainability, circular economy models, and digital infrastructure for agricultural supply chains. The fast-changing nature of blockchain itself requires continuous academic engagement and research should monitor technological innovations and improvements. Blockchain technology continues to be recognized as a foundational tool for the future of decentralized and transparent value chains, yet its current level of implementation in industry remains relatively low. Many of its real-world applications are at an early stage, and their full potential can only be unlocked through targeted research, systematic testing, and strategic cross-sector collaboration.

Another key area of exploration lies in the development of circular value chains. The global coffee industry generates over 40 million tons of waste annually, an amount equivalent to seven times the weight of the Great Pyramid of Giza. A significant share of this waste, approximately 72%, originates in coffee-producing regions, making Africa uniquely positioned to benefit from circular economy models that convert waste into economic value.[90] Traditionally, by-products such as coffee pulp, husks, parchment, and spent grounds have been discarded. However, they hold substantial untapped potential across industries, including food and beverage, cosmetics, agriculture, water treatment, and renewable energy. As ICO Executive Director Vanusia Nogueira stated, "We must rethink the notion that value is only derived from coffee beans."[91] Africa has the opportunity not just to mitigate waste but to transform it into economic assets that empower rural communities, protect the environment, and enhance value creation at origin. Therefore, pressing global challenges such as resource scarcity, climate instability, and shifting market regulations demand innovative frameworks that go beyond linear models of value creation. Further research on blockchain-supported circularity could unlock new income models for smallholder farmers while contributing to climate resilience. By rethinking the use of resources, from coffee by-products to digital energy footprints, African economies can move toward a regenerative trade model that not only creates financial value but also strengthens environmental resilience and social equity. To accelerate these transformations, the International Coffee Organization (ICO), in collaboration with the International Trade Centre (ITC), the Lavazza Foundation, and academic institutions

[90] African Fine Coffees Association (Review Magazine Volume 14), p.23
[91] African Fine Coffees Association (Review Magazine Volume 14), p.25

such as Politecnico di Torino and University College London, developed a strategic roadmap for circular coffee economies in its 2024 flagship report "*Beyond Coffee: Toward a Circular Coffee Economy"*. The report outlines several key actions: integrating regenerative agriculture practices, training farmers in circular techniques, establishing living income benchmarks and incentive schemes, investing in research and development for waste valorization, and promoting local value addition through on-site roasting and instant coffee production. Sustainable packaging aligned with regional waste management policies and the promotion of certified circular coffee products are also recommended to drive market transformation.[92] Coffee by-products can be repurposed into high-value applications: coffee husks can be used in tea, syrups, and gluten-free flour; spent grounds serve as an ideal base for mushroom cultivation; coffee husks can be processed into biochar, improving soil fertility and carbon sequestration; pulp can be used in anaerobic digesters to produce biogas and organic fertilizer; and other waste can be transformed into organic compost or processed into fuel briquettes. Moreover, biosorbents made from coffee waste are being explored for their capacity to remove pollutants from wastewater, further expanding the environmental benefits of upcycling.

Closely tied to this is the growing relevance of technology-driven efficiency improvements in farming itself. Future research should examine how blockchain infrastructure, when integrated with advanced agricultural technologies like precision irrigation systems, soil sensors, or AI-assisted input recommendations, can optimize resource use, reduce environmental impact, and increase yield predictability. These innovations, supported by transparent, real-time data flows, may enable more sustainable and efficient farming systems in regions with limited access to traditional agronomic expertise.

Another important field involves cross-chain interoperability, which is essential for building inclusive, scalable ecosystems. Future research should investigate how payment systems and traceability architectures can operate seamlessly across different blockchain networks to maximize flexibility and accessibility without compromising data integrity or compliance. Establishing interoperability with existing Enterprise Resource Planning (ERP) systems presents a key opportunity to streamline operations. By connecting blockchain-based traceability and payment infrastructures with widely used ERP platforms like SAP, organizations can unify sustainability reporting, financial data, and compliance documentation within a single, verifiable framework.

[92] African Fine Coffees Association (Review Magazine Volume 14), pp.24-25

See also Appendix E for more details regarding a tokenization approach of SAP itself. Future research should therefore explore standardized APIs, smart contract templates, and cross-chain identity protocols that support seamless integration with legacy enterprise software, enabling companies to scale blockchain adoption without disrupting core business functions.

Potential funding mechanisms and subsidy programs also warrant deeper analysis in terms of enabling public-private partnerships to accelerate technology adoption in the Global South. In this context, targeted subsidy schemes could play a transformative role in bridging financial gaps that currently hinder the implementation of blockchain-based systems in rural and resource-constrained regions of the African continent. Funding programs linked to ESG performance metrics could incentivize sustainable farming practices and digital compliance, creating a financial rationale for early adoption. Future research should explore how multilateral development institutions, climate finance instruments, and bilateral trade partnerships might be aligned with compliance regulations to support such subsidy structures.

Ultimately, the integration of blockchain-based systems into agricultural supply chains, when supported by sustainable funding, cross-sector collaboration, and forward-looking policy frameworks, offers not only a technological innovation, but a structural opportunity to redefine fairness, transparency, and participation of Ethiopian coffee farmers in global trade.

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Appendix

A. Consensus Mechanisms: Proof-of-Work, Proof-of-Stake & Proof-of-Authority

The consensus mechanism is a fundamental element in any blockchain network. It ensures that all participants agree on the current state of the distributed ledger and that only valid transactions are recorded. This process is critical for achieving security, reliability, and decentralization within the system. There are several consensus algorithms available, each with distinct technical requirements, advantages, and use cases. The most prominent among these are Proof-of-Work (PoW), Proof-of-Stake (PoS), and Proof-of-Authority (PoA).

Proof-of-Work, as implemented by Bitcoin, was the first widely adopted consensus algorithm and remains the most recognized. In this model, network participants, known as miners, compete to solve complex cryptographic puzzles. The first to solve the puzzle earns the right to validate a block of transactions and append it to the blockchain, receiving a reward in cryptocurrency. One of the strengths of Proof-of-Work is its high level of security. An attacker would need to control more than 50% of the total network's computing power (a so-called 51% attack), which is prohibitively expensive in large networks like Bitcoin. However, it also faces significant criticism due to its high energy consumption, environmental impact, and limited scalability.[93]

Proof-of-Stake, developed as an energy-efficient alternative to Proof-of-Work, replaces the competition-based validation with a system where validators are selected based on the amount of cryptocurrency they hold and "stake" in the network. The higher the stake, the more likely a participant is chosen to validate the next block. This approach drastically reduces energy consumption and hardware requirements, making it more sustainable. However, it introduces risks of centralization, as wealthier participants may dominate validation. To address this, many implementations introduce mechanisms like randomized validator selection and "coin age" to balance participation and fairness.[94]

This distinction is critical when evaluating blockchain solutions for real-world applications. Proof-of-Stake is increasingly relevant in sectors such as supply chain management and financial services, where energy efficiency, low costs, and scalability are prioritized over maximum decentralization. Blockchains such as Solana exemplify

[93] Cointelegraph (Proof-of-stake vs. Proof-of-work)
[94] Cointelegraph (Proof-of-stake vs. Proof-of-work)

Proof-of-Stake systems that are optimized for these parameters and will be explored further in this thesis.

Proof-of-Authority, by contrast, operates under a more centralized approach and is commonly used in private or consortium blockchain networks. In Proof-of-Authority systems, trusted authorities, typically selected entities or individuals are pre-approved to validate transactions and create blocks. These validators are identifiable and held accountable, which enhances trust within a closed ecosystem. The main advantage of Proof-of-Authority is its efficiency. It consumes minimal energy, offers high transaction throughput, and provides fast finality, making it especially attractive for enterprise and government use cases. However, this centralization undermines the original decentralized ethos of blockchain and raises concerns about censorship resistance and single points of failure.[95]

From a business perspective, the choice of consensus mechanism depends heavily on the desired balance between decentralization, scalability, energy efficiency, and trust assumptions. For public supply chains involving multiple unknown stakeholders, Proof-of-Stake may strike the right balance. In contrast, private industrial consortia or logistics networks may benefit more from Proof-of-Authority due to their control and speed. This fundamental difference in validation mechanisms is essential for understanding why certain blockchains are better suited for scalable applications such as supply chain payments and real-time transaction processing.

[95] Cointelegraph (Proof-of-authority vs. Proof-of-stake)

B. Comparative Overview of Blockchain-Based Payout Mechanisms

Criteria:	M-Pesa Offramp Integration	Direct Stablecoin Wallet
Payout Infrastructure:	Mobile money via M-Pesa using third-party offramp providers (e.g., Moonpay)	Blockchain wallet accessed via smartphone (no third-party payout infrastructure)
Initial Setup Complexity:	Medium: Requires integration of offramp services and KYC alignment	Low: Requires wallet app setup and basic onboarding
Recurring Transaction Costs:	1–1.5% M-Pesa fees per transaction + off-ramp conversion margin	~$0.00064 USD per transaction (Solana network)
Inflation Protection:	Vulnerable to local currency devaluation (ETB payout)	Protected through USD- or EUR-pegged stablecoins
Regulatory Exposure:	Complies with local payment systems; may be subject to mobile money regulation	Subject to crypto/stablecoin frameworks; not yet regulated in Ethiopia
Farmer Accessibility:	High: Suitable for digitally inexperienced users familiar with mobile money	Medium: Requires digital literacy and smartphone access
Compliance & Traceability:	Offramp not natively traceable; compliance dependent on intermediary partners	Full on-chain transparency via smart contracts and traceable tokenized payouts
Cross-border Compatibility:	Limited to regions with local M-Pesa support	Globally scalable; independent of local telecom/payment infrastructure
Long-term Strategic Benefit:	Inclusive access, transitional bridge solution	Optimal for cost-efficiency, inflation protection, and full financial autonomy

C. Use Case: Farmer Connect

Farmer Connect is a Swiss-based technology company that delivers end-to-end traceability solutions to global agricultural supply chains, with a particular focus on digitalization, data integrity, and ESG compliance. At the core of its approach lies the belief that farmers themselves must be placed at the center of digital ecosystems in order to generate reliable data, reduce inefficiencies, and create shared value. As stated by Michiel Hendriksz, Founder and Director of the Farmstrong Foundation: "*One of the biggest issues faced on the ground at origin is the cost and quality of data collection & verification.*"[96]

Founded in 2019, Farmer Connect aims to address these challenges by using blockchain technology to create a secure and decentralized record of every transaction in the coffee supply chain. Farmer Connect actively aligns its operations with the United Nations Sustainable Development Goals, specifically contributing to SDG 12 (Responsible Consumption and Production), SDG 8 (Decent Work and Economic Growth), and SDG 9 (Industry, Innovation and Infrastructure) by promoting transparent value chains, inclusive farmer participation, and scalable digital infrastructure.[97]

The following image shows four of the most important issues Farmer Connect is offering solutions for.

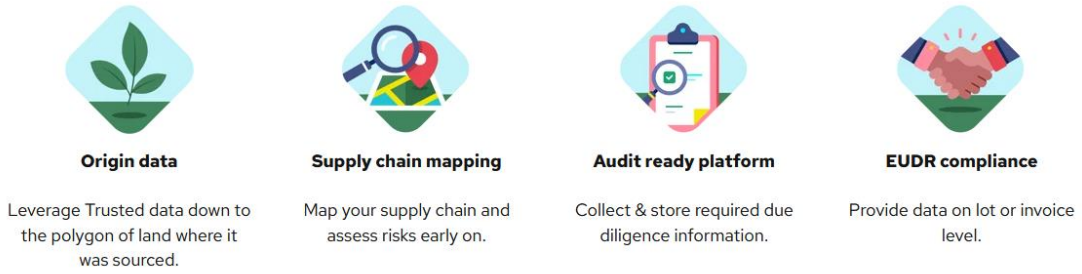

Image 14: Farmer Connect (EUDR-Solutions)

One key issue is data accuracy and validation. If an entity records false information regarding the quality or sustainability of a batch of coffee, the blockchain itself cannot correct this error, which underscores the need for reliable verification mechanisms at the point of data entry.[98]

To support data integrity and regulatory compliance, Farmer Connect developed the FarmerID system, a self-sovereign digital identity that gives farmers control over their data. For example, in a pilot involving over 2.000 Rwandan farmers, Ethereum was

[96] Farmer Connect (White Paper), p. 3
[97] Farmer Connect (White Paper), p. 9
[98] Farmer Connect (EUDR-Solutions)

used to link satellite-verified deforestation data to coffee traceability records. These trust ratings are stored as verifiable credentials on the blockchain and can be linked to specific product batches, allowing brands to prove environmental compliance and target ESG interventions more effectively.[99]

In addition, Farmer Connect developed the "Thank My Farmer" application, which allows individuals to scan a QR code on their coffee packaging and retrieve a full traceability report on the blockchain, to engage with consumers more directly.

The app also enables consumers to contribute directly to community-driven projects in coffee-growing regions, such as reforestation programs, clean water initiatives, or education support for farming families.[100] The Ethereum blockchain plays a key role in enabling these direct contributions through transparent smart contract-based transactions, ensuring that donations reach their intended recipients without intermediaries taking excessive fees or manipulating fund allocations.

This blockchain-based traceability solution represents a significant step toward greater accountability and sustainability in global trade, paving the way for even more streamlined and inclusive data management. Technically this approach could be considered as a partly solution to the problem statement stated in this thesis, although it is not complete nor the most efficient one. Financial transactions and compensation from the farmers are not covered at all. Nevertheless, a positive impact and cost reduction on the farmer´s and importer´s side are created. On the other hand, it may serve as a blueprint for developing future systems, particularly for programming smart contracts that enforce deforestation-related compliance criteria, such as geolocation verification, certification tracking, and automated due diligence reporting aligned with EUDR requirements.

[99] Farmer Connect (White Paper), pp. 5-8
[100] ThankMyFarmer (Official Website)

D: Use Case: AgriDex

As stated by Henry Duckworth, co-founder and CEO of AgriDex: "*Many of the world´s farmers are underpaid, and the environmental impact of trade is poorly understood. A primary goal of the Agridex system is to ensure better and more profitable payments for farmers, while also offering financing based on their declared trade flows.*"[101] Therefore, AgriDex offers a compelling model for modernizing agricultural trade through the Solana blockchain technology, with a strong focus on operational efficiency, transparency, and regulatory alignment. One of its core advantages lies in significantly reduced transaction costs. Global payments conducted through the platform incur fees below 0.5%, in contrast to the 3–6% commonly charged in traditional remittance channels. Settlement occurs in near real time, averaging around five seconds, whereas conventional cross-border transfers can take several business days. By leveraging autonomous document verification and immutable origin tracking, AgriDex minimizes fraud and ensures accountability throughout the supply chain. Furthermore, the platform enhances visibility and consumer confidence by storing detailed provenance, environmental, social, and governance credentials on-chain, making them easily accessible at the point of sale. Finally, the platform's architecture promotes fair access by requiring only a basic internet connection, significantly lowering barriers to entry for smallholder producers engaging in international trade.[102] In December 2024, AgriDex launched its $AGRI token, introducing a decentralized governance model to its Solana-based agricultural marketplace. The token debuted with a total supply of 1 billion units, each priced at $0.065 USD, resulting in an initial market valuation of $65 million. Projections as shown in the figure below indicate that by end of 2026, AgriDex aims to generate approximately £20 million, which is ten times the amount as of end of 2025. By 2028, the platform expects to achieve a profit of £133 million, which is around 66 times the amount as of end of 2025.[103]

[101] Cointelegraph (How Solana is transforming agricultural trade)
[102] AgriDex (Official Website)
[103] Cryptoslate (Press releases AgriDex)

Image 15: Cryptoslate (Press releases AgriDex)

One early proof of concept comes from Oldenburg Vineyards in South Africa, where CEO Adrian Vanderspuy reported: "*The funds came into our AgriDex account in seconds rather than days, and the fees were 5 British pounds ($6.45 USD). We look forward to continuing our partnership and bringing more of our stock onchain.*"[104] Examples like this highlight how blockchain-based trade platforms can perform in real world agricultural trade. AgriDex also was awarded of Stand With Crypto UK´s "Best Use Case" award.[105] In addition, as stated by the AgriDex Foundation: "*Agridex believes that education is key to informing peoples on the better production of food*". In line with its commitment to social impact and referring to the statement above, AgriDex allocates 5% of its international profits to the AgriDex Foundation, which supports farmer education and sustainable agriculture, reinforcing the platform´s long-term vision to empower rural communities and drive systemic change across the agricultural sector.[106]

[104] Cointelegraph (How Solana is transforming agricultural trade)
[105] Cryptoslate (Press releases AgriDex)
[106] AgriDex (Official Website)

E. The Dimitra Case – Blockchain-Based Infrastructure for Smallholder Coffee Farmers in Indonesia

As stated by Jon Trask, CEO of Dimitra: "*Every smallholder farmer, regardless of economic status, should be able to benefit from simple, beautiful, and useful technology… because when farmers thrive economies thrive.*"[107]

Therefore, the Dimitra (DMTR) case offers a highly relevant and forward-looking example of how blockchain, tokenization, and integrated digital technologies can support smallholder farmers in emerging markets, connected with the context of coffee production. While the focus of this thesis lies on the implementation of Solana-based blockchain payment systems in the Ethiopian coffee sector, the Dimitra use case from Indonesia serves as a complementary example on the Ethereum blockchain and supports several key assumptions made throughout the research. The Indonesian coffee sector shares many structural similarities with Ethiopia's: smallholder-dominated production, fragmented supply chains, and a lack of access to real-time market data, technical services, and fair pricing mechanisms.[108] Dimitra addresses these challenges through a comprehensive digital agriculture platform, combining blockchain with AI and IoT-based monitoring tools. Farmers are equipped with a mobile application that offers agronomic advice, weather forecasts, and production tracking features, while each transaction and sustainability-relevant event in the supply chain is tokenized and immutably recorded on a blockchain ledger.

Crucially, Dimitra´s model introduces tokenized traceability not just for product movement, but for a wide array of sustainability attributes, such as regenerative practices, emissions data, or soil health. This is achieved via so-called "digital twin tokens," which capture physical and environmental characteristics of agricultural outputs and persist across multiple processing and ownership stages. These tokens not only enable end-to-end supply chain traceability but also unlock access to new types of financial services. As outlined in recent field trials, Dimitra´s platform allows farmers to document their credibility, which can be used by lenders and insurers to assess risk more accurately, thus closing a major trust and data gap in rural finance.[109] An existing and well-established token like Dimitra, which is already listed on several exchanges, can also be used to raise capital and thus lay the foundation for investments in the agricultural sector. This multidimensional approach could serve as a blueprint

[107] Dimitra (Official Website)
[108] Cointelegraph (Blockchain in the coffee supply chain)
[109] Cointelegraph (Blockchain in the agrifood sector)

for further developments in Ethiopia and other African countries, particularly in regions seeking to align smallholder production with EU regulatory frameworks.

For these reasons, the Dimitra use case has been included as a supplementary reference in the appendix of this thesis. It serves not only as a validation of blockchain´s relevance in agri-food systems but also as an example of systemic innovation at the intersection of technology, finance, and sustainability. Its inclusion supports the thesis´ broader argument that the future of ethical coffee sourcing lies in interoperable, decentralized, and data-driven ecosystems, where value is not only measured in beans exported but in verified practices, transparent supply flows, and inclusive market access**.**

F. SAP Green Token

SAP´s Green Token platform introduces a highly configurable digital infrastructure that enables companies to manage sustainability declarations, supply chain transparency, and compliance reporting in a scalable and audit-ready manner. At its core, the system provides centralized declaration management by collecting, generating, and distributing sustainability declarations automatically across multiple operational layers, including sites, facilities, and individual materials. Using customizable templates and flexible configuration tools, companies can align their data processes with international standards while significantly reducing administrative workload. The SAP Green Token platform enables companies to credibly demonstrate progress on their ESG commitments by tracking raw material blends and providing verifiable sustainability data across the supply chain. This not only positions stakeholders as leaders in the fight against greenwashing but also allows them to proactively share audit-ready evidence with partners and regulators. By embedding ESG transparency directly into operational workflows, the platform reduces reliance on manual data collection and streamlines compliance with evolving sustainability standards. Cloud-based architecture further accelerates implementation: organizations can integrate the system rapidly into their core environments, without requiring a full prior mapping of the supply chain, thus ensuring agility, scalability, and risk mitigation from day one.[110]

One of the platform´s key strengths is its ability to support various accounting models such as mass balance and segregated bookkeeping. This allows users to dynamically map sustainability credits to products and ensure traceability in line with evolving regulatory frameworks like the German Supply Chain Due Diligence Act and the EU Deforestation Regulation (EUDR). Through attribute-based filtering and configurable conversion mechanisms, Green Token facilitates real-time credit allocation and transparent transfer tracking throughout the supply chain. In terms of data integration, the system automatically captures input from ERP environments and dynamically assigns sustainability attributes to upstream suppliers. This allows for seamless traceability and ensures that each material flow is linked to verified sustainability claims. Moreover, the platform supports real-time audit preparation and reporting functionalities, enabling companies to generate certification-compliant documentation, track material origin and movements, and monitor balance sheets and

[110] SAP Germany Products (SAP Green Token)

sustainability statements over time. These insights empower organizations to act proactively and stay ahead of compliance challenges.[111]

What distinguishes Green Token from many other blockchain platforms is its seamless integration with existing enterprise resource planning (ERP) systems, notably SAP S/4HANA and ECC6.0. This allows companies to board the solution without abandoning legacy systems, enabling a modular and scalable tokenization layer, due to the interoperability provided. Sustainability data and token exchanges can be embedded directly into business processes, such as procurement, certification, and audit management. The images shown below are examples of the SAP dashboard, showing some features when operating with the Green Token system:

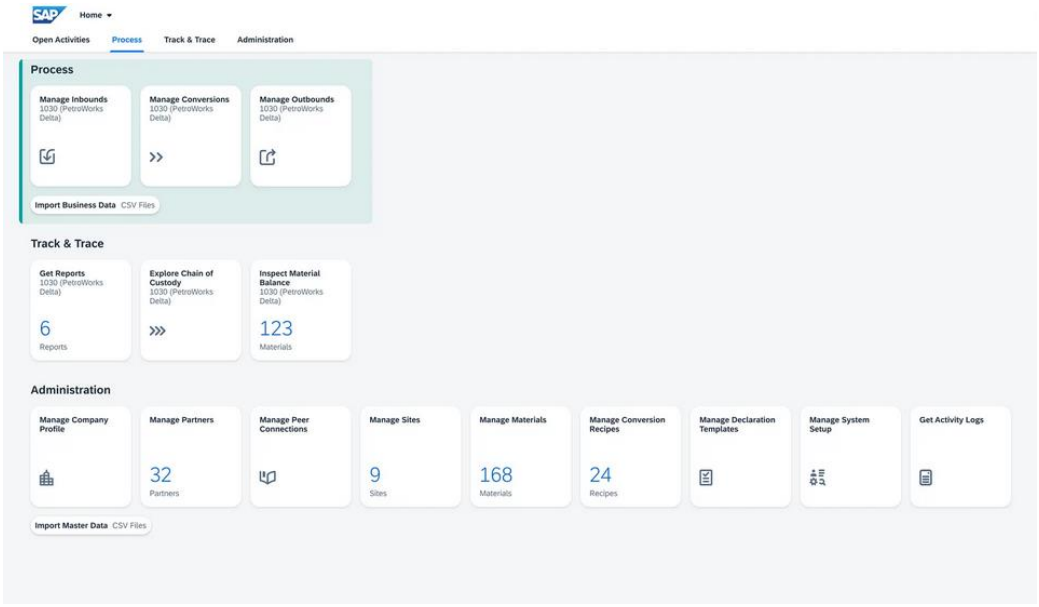

Image 16: SAP Germany Products (SAP Green Token Features)

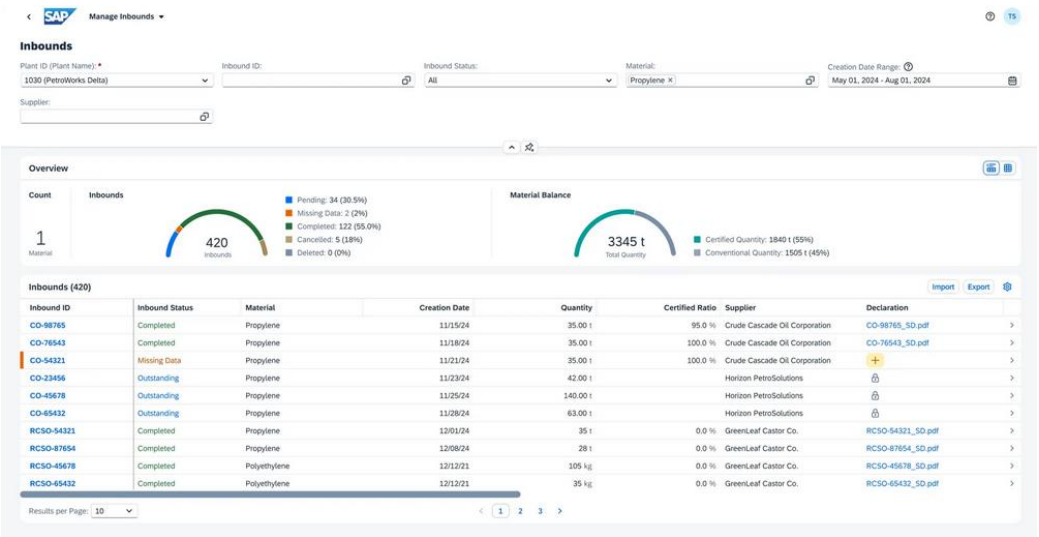

Image 17: SAP Germany Products (SAP Green Token Features)

[111] SAP Germany Products (SAP Green Token Features)

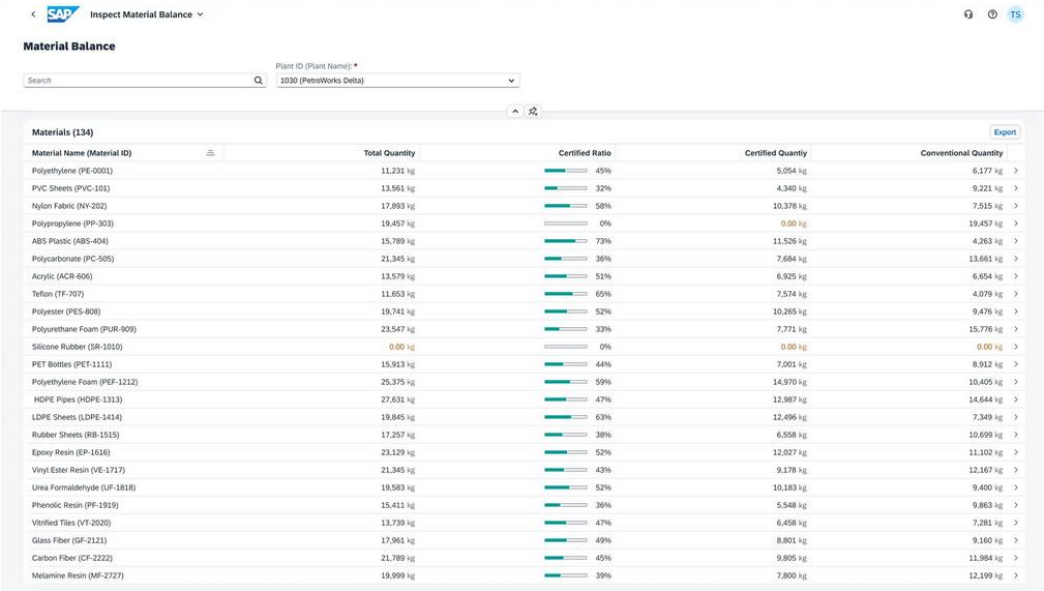

Image 18: SAP Germany Products (SAP Green Token Features)

In summary, SAP Green Token offers a concrete and highly relevant example of how tokenization can serve as an infrastructure bridge between circular economy principles, sustainability claims, and digital payment logic. The tokenization approach provided by SAP focuses more on the European importer and company side, than on the Ethiopian coffee farmers itself. Nevertheless, its model could serve as a blueprint for future blockchain applications in the agrifood domain, providing both the technical and governance architecture necessary to operationalize the ideas explored in this thesis. The SAP Green Token case shows, that big companies already acknowledged the potential of connecting blockchain technology and tokenization with agriculture production.