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DOI
10.3390/futuretransp4030037

Publication date
2024

Document Version
Final published version

Published in
Future Transportation

Citation (APA)
Tadesse, M. D., Gebresenbet, G., Ljungberg, D., & Tavasszy, L. (2024). Digital Traceability Capabilities: The Case of the Ethiopian Coffee Supply Chain. *Future Transportation*, *4*(3), 780-794. https://doi.org/10.3390/futuretransp4030037

future transportation

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Digital Traceability Capabilities: The Case of the Ethiopian Coffee Supply Chain

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Abstract: Digital technologies are essential tools that enable traceability in supply chains. In low-income countries, traceability represents a challenge due to the complicated structure of supply chains and the involvement of multiple stakeholders. This research developed a framework for a digital traceability system (TS), using the Ethiopian coffee supply chain as a case study. A literature review was conducted to gain an in-depth understanding of state-of-the-art digital traceability technologies. A logistics audit was conducted to map the coffee supply chain in Ethiopia and evaluate the implementation level of traceability technologies. Although the implementation of traceability technologies in the Ethiopian coffee supply chain is low, the results revealed that the usage of traceability technologies improves downstream of the supply chain. The traceability framework developed in this study ranges from a paper-based TS to a fully digitalised TS. The implementation of a TS in the coffee supply chain of Ethiopia is met with several challenges such as affordability, limited awareness, resistance of certain stakeholders, infrastructure limitations, restricted accessibility of some technologies and insufficient policy frameworks. Stakeholders from low-income countries can use the framework developed in this study to adopt a TS for their supply chains in line with their needs and current digitalisation levels.

Keywords: coffee; digital traceability; Ethiopia; logistics audit; low-income countries; supply chain

Citation: Tadesse, M.D.; Gebresenbet, G.; Ljungberg, D.; Tavasszy, L. Digital Traceability Capabilities: The Case of the Ethiopian Coffee Supply Chain. *Future Transp.* **2024**, *4*, 780–794. https://doi.org/10.3390/futuretransp4030037

Academic Editor: Kum Fai Yuen

Received: 30 April 2024
Revised: 24 June 2024
Accepted: 5 July 2024
Published: 12 July 2024

1. Introduction

Quality management is a crucial component of supply chain management, ensuring that companies deliver the right product to the right customer in optimal condition. Providing quality products not only enhances customer satisfaction but also promotes sustainability by reducing losses and minimising environmental impact. The ISO 9001:2015 standard for quality management highlights the importance of product identification and traceability, as well as effective information management and documentation, as key requirements for maintaining product quality [1].

Traceability, being an important aspect of quality management, is vital in supply chains as it provides stakeholders with information about the product they receive and gives consumers information about the product they consume. It enables stakeholders in the supply chain to identify the history and location of a product [2]. Through traceability, supply chain members can identify the origin of the product, the means of transportation used and the storage conditions [3,4].

The food industry, in particular, has attracted considerable attention regarding traceability due to multiple food-borne disease outbreaks and food recalls [5–7]. As a result, the use of a traceability system (TS) is important in food supply chains as it allows better inventory management and improved product monitoring [8]. Other benefits of having a food TS include greater consumer confidence in the product being bought, improved food recall and better food crisis management [5].

The transfer of correct information among supply chain members is vital for a successful TS [5]. This can be achieved by implementing a simple system that archives documents manually [9]. However, manual systems are labour-intensive, time-consuming and leave many paper trails [10]. Alternatively, technologies could be implemented to enable traceability [8]. TSs supported by technologies are more advanced than simple systems since they make product identification and verification easier. Technologies such as barcodes and quick-response (QR) codes can be used to identify products and this information is then sent to databases created by companies [9].

Stakeholders can also develop an integrated TS, where all supply chain members input their information into a common database [9]. One example of an integrated TS is a TS based on blockchain. Blockchain facilitates the transaction of immutable information among stakeholders [11]. It also eliminates the need for central authorities to validate transactions [12] and instead uses the consensus reached among stakeholders to make a transaction valid. Other technologies that enable integrated TSs and can be used along with blockchain are radio-frequency identification (RFID) and the Internet of Things (IoT). The integration of these technologies with blockchain enhances transparency and visibility in the supply chain [13].

The level and advancement of traceability attained varies between countries based on their government regulations [7], the needs of consumers [9,14] and the financial capabilities of stakeholders. In low-income countries, the adoption of TSs supported by digital technologies presents something of a challenge because their supply chains are traditional, making digitalisation a resource-intensive activity [15]. The poor communication and coordination among stakeholders [16] and the relatively high cost of implementing such a system prevent stakeholders in low-income countries from adopting digital TSs. Other challenges facing the implementation of a digital TS in low-income countries include the interoperability of the technology solution with the existing system and the affordability of the technology [17]. Despite these challenges, firms in low-income countries can benefit from adopting digital TSs. Some of the advantages include having better food recall and food crisis management, improving the transparency of their supply chains and having a competitive advantage not only locally but also in the global market [7].

In the context of low-income countries, there is a lack of research exploring digital needs along food supply chains. Specifically, studies focusing on the adoption of digital traceability technologies within the coffee supply chain of these countries are lacking. Therefore, this paper aims to address this research gap by examining the digital traceability capabilities of low-income countries by assessing the current level of digital technology adoption for traceability using Ethiopia, a major coffee-producing region, as a case study. Furthermore, the paper develops a framework for a digital TS that could serve as a roadmap for stakeholders looking to implement digital TSs in their supply chains.

The remainder of this paper is structured as follows. In Section 2, a literature review is presented. In Section 3, the methodology followed in this study is described. Next, in Section 4, an introduction is given about the Ethiopian coffee supply chain. In Section 5, the results of this study are presented while in Section 6 the discussion is presented. Finally, in Section 7, the conclusions and recommendations are provided.

2. Literature Review

2.1. The Global Coffee Market

Coffee is one of the most highly traded agricultural commodities globally [18]. In 2022, about 175.6 million bags of 60 kg coffee were consumed worldwide [19]. The top five coffee-producing countries, according to the ICO [20], are Brazil, Colombia, Indonesia, Vietnam and Ethiopia. Most countries that import coffee from these coffee-growing regions enhance the value of green coffee beans through processing activities such as roasting, blending and grinding. These processed coffee products are then exported to other nations worldwide [18].

The global coffee supply chain is composed of two main types of countries: exporting countries and importing countries. The coffee-exporting countries are mostly developing countries located in South America, Asia and Africa, while most importing countries are located in North America and Europe [21]. Coffee production and processing conducted in most exporting countries is labour-intensive, while processing conducted in importing countries is capital-intensive [22]. According to Kiwanuka [21], 70% of the world's coffee is grown by 25 million small-scale producers. Despite the substantial revenue generated from coffee sales globally, stakeholders located outside the coffee-growing regions obtain a disproportionate share of the income. As a result, smallholder farmers receive only a small fraction of the revenue generated.

2.2. Traceability Systems

According to Bosona and Gebresenbet [5], a successful TS must be able to trace and track the product and provide information about its history as it moves along the supply chain. This can be achieved using numerous TSs that vary based on the type of technology used and the required level of digitalisation in the supply chain.

According to Manos and Manikas [16], there are two types of TS based on how product information is collected and stored: paper-based and IT-based TSs. Paper-based TSs are the simplest and widely implemented form of TS [5,16]. In this type of system, a person manually assigns alphanumerical codes to identify products [23]. The challenge with this type of TS is that it is time-consuming [23]. Furthermore, with such a TS, it is difficult to synchronise data from different stakeholders along the supply chain, thereby increasing the chance of data loss and mismanagement [24].

IT-based TSs leverage the recent advances in digitalisation and automation. Automating data collection is a key task in IT-based TSs. This can be achieved with technologies such as barcodes and QR codes [23]. RFID tags are also used for product identification and are more advanced than barcodes and QR codes as they enable automated identification of products with little to no human intervention. Some of the advantages of an RFID system are that it can store more information than barcodes and QR codes, has the ability to read multiple tags at the same time and has a high speed of reading [23].

Blockchain, one of the technologies that enable digital traceability, facilitates the transaction of immutable information among stakeholders [11]. This aids in avoiding the discrepancies and disputes that usually occur in supply chains about traceability information [25]. Blockchain eliminates the need for central authorities to validate transactions [12] and instead uses the consensus reached among stakeholders to make a transaction valid. According to Bumblauskas et al. [11], blockchain can enhance the transparency and quality of products along supply chains while being able to engage the consumers in the product that they are buying. Blockchain adds value to supply chains by enabling traceability, certifications, tracking and verification [12]. Thus, it is a powerful technology that can disrupt supply chains.

To improve traceability in supply chains, blockchain is integrated with other technologies [26] such as QR codes to allow the identification of provenance along the supply chain [27] and give consumers more information about the product they are purchasing. Consumers can use their mobile phones to scan the QR code on the package [28], which can help them ensure that the product they are selling is safe, legitimate and authentic [29]. The Internet of Things (IoT) can also be used with blockchain to enable digital traceability. With the help of wireless sensor networks (WSNs), it is possible to control and monitor the humidity and temperature of products [30]. In addition, a geographic positioning system (GPS) can be used to provide location information about products along the supply chain [31].

2.3. Previous Works

Traceability in the agri-food sector has been studied by multiple researchers. Collart and Canales [25] explored the implementation of blockchain in the agri-food supply chain.

The authors argued that the adoption of blockchain helps ensure traceable supply chains while also addressing major challenges in the agri-food supply chain, such as food fraud and wastage. Despite blockchain's capabilities, they noted that the accuracy of information shared on the blockchain is highly dependent on the data provided by participants. Additionally, the fragmented nature of the agri-food supply chain and the predominance of small-scale producers could inhibit the adoption of this technology.

Herrera and Orjuela-Castro [8] assessed various traceability systems for the mango supply chain in Colombia. They evaluated different alternatives that could facilitate the adoption of traceability technologies by simulating inventory and food quality. Their study concluded that the mango supply chain performed better when homogenous traceability technologies were utilised.

Tan et al. [13] developed a traceability framework based on blockchain for halal supply chains. Their framework is integrated with QR codes and smart contracts, ensuring the integrity of halal foods is maintained in the supply chain, free from contamination. Furthermore, several researchers including Duan et al. [32], Kelepouris et al. [24], Mosquera and Piedra [33], Tan and Ngan [26] and Wang et al. [34] have developed frameworks for the integration of technologies such as RFID and blockchain into supply chains to enhance traceability.

Research focusing on traceability in the coffee supply chain includes the work of Bettín-Díaz et al. [35], who developed a methodological framework for the implementation of blockchain to ensure food traceability, using the Colombian coffee supply chain as a case study. Bravo et al. [9] analysed the traceability of the coffee supply chain to ensure sustainability. Gligor et al. [27] assessed the implementation of blockchain technology to ensure transparency in the coffee supply chain. Karami et al. [36] examined the impact of digitalisation and certification on coffee farmers in Indonesia, finding that certification has less impact on digital technology adoption for these farmers.

In summary, there is a substantial body of literature on traceability and its impact on the agri-food supply chain, particularly the coffee supply chain. However, studies assessing the current digitalisation level of the coffee supply chain in low-income countries to improve digital traceability are still limited.

3. Methodology

In this research, a framework depicting the integration of digitalisation in the Ethiopian coffee supply chain to enable digital traceability was developed. To achieve this objective, a qualitative approach was utilised. Qualitative research is conducted to gain a comprehensive understanding of specific phenomena or processes [37,38]. This approach focuses on obtaining detailed information by concentrating on smaller samples, favouring depth over breadth [39]. This could be achieved by gathering data from individuals or groups through interviews [40].

Initially, a literature review was first conducted in this research to gain an in-depth understanding of state-of-the-art digital traceability technologies. Following this, a logistics audit was carried out as part of the qualitative research approach to map the coffee supply chain in Ethiopia and evaluate the level of implementation of traceability technologies.

The logistics audit in this study comprised two main activities: interviews with key informants and field visits. Interviews were conducted with 8 smallholder farmers from the Sidama region, 30 exporters (12 of whom had commercial farms in various regions of Ethiopia), 10 transportation companies responsible for transporting coffee beans from different regions in Ethiopia to the capital city, Addis Ababa, and from Addis Ababa to the port of Djibouti, 1 large-scale coffee processing firm and 5 key informants from the Ethiopian Coffee and Tea Authority and the Coffee Liquoring Unit (CLU). Field visits involved visiting smallholder coffee farms, coffee washing stations, the large-scale coffee processing firm and the CLU.

The interview questions for the logistics audit were formulated based on the studies on logistics audits by Bosona and Gebresenbet [41], Sekulová et al. [42] and Božičnik et al. [43].

In this study, the logistics audit was primarily used to establish the digital traceability capabilities of the Ethiopian coffee supply chain. This helped identify parts of the supply chains where stakeholders use traceability-enabling technologies. Additionally, the logistics audit helped map the flow of information from one stakeholder to the next, which in turn facilitated the construction of the traceability framework for the Ethiopian coffee supply chain.

The primary data collected through the logistics audit were also supplemented by secondary data. These included information from the Ethiopian Coffee and Tea Authority, a government organisation responsible for regulating the production, processing, grading and export of coffee, and the International Coffee Organization (ICO). These data helped identify the production and export potential of Ethiopian coffee, as well as its share in the international market.

Finally, a framework for a digital TS for the Ethiopian coffee supply chain was developed based on the results of the literature review and the logistics audit. The methodology followed in this study is summarised in Figure 1.

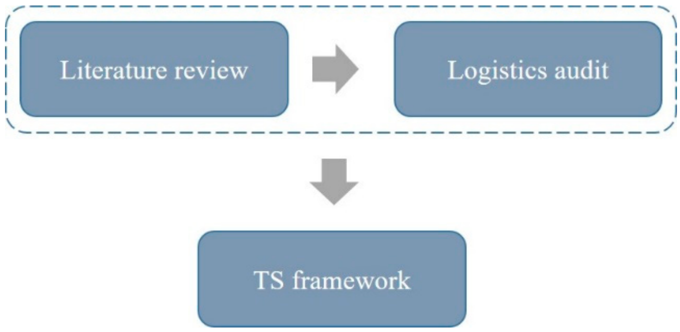

Figure 1. The methodology followed in this research.

4. Case: The Coffee Supply Chain of Ethiopia

Ethiopia is one of the major coffee-growing regions of the world and accounts for the largest coffee production in Africa and the fifth largest in the world [20]. The country is considered the birthplace of Arabica coffee [44]. Coffee is an important cash crop in Ethiopia, impacting the livelihoods of over 10 million Ethiopians either directly or indirectly [45]. The country also has one of the highest levels of domestic coffee consumption, with locals consuming 50% of the production [46].

In 2020, coffee contributed 28.6% of the country's exports, followed by flowers (14.1%) and oilseeds (11.5%) [47]. According to the Ethiopian Coffee and Tea Authority [48], the major export destinations for Ethiopian coffee are Saudi Arabia, the United States of America, Germany, Belgium and South Korea. The coffee exported to these regions is usually in the form of green beans.

There are numerous coffee-growing regions in Ethiopia, with most coffee production concentrated in the Oromia region and in the Southern Nations, Nationalities and Peoples region (SNNPR) (Figure 2). The coffee grown in these regions is harvested and transported primarily to the capital city, Addis Ababa, where it is processed, quality tested and prepared for export. Thus, the majority of the coffee exporters in the country are in Addis Ababa.

In Ethiopia, the two most common coffee processing techniques are the wet process and the dry (natural) process. During the wet process, coffee cherries are depulped to remove the outer layer, sorted, fermented and finally washed to remove the mucilage. Coffee beans extracted during this process are then taken to drying beds and left in the sun to dry until they reach a moisture level between 10% and 12% [49]. The dry (natural) process involves fewer steps as freshly picked coffee cherries are sorted and placed on drying beds. Once they are completely dry, the beans are extracted from the dried cherries by hulling. Compared with dry (natural) coffee, washed coffee results in homogeneous coffee with fewer defects [50]. Although the coffee obtained from the washed process is of better quality, the process is resource-, labour- and time-intensive [51].

Previous research focusing on the Ethiopian coffee supply chain has attempted to shed light on several issues. For instance, Worako et al. [52] investigated the volatility of coffee prices in Ethiopia, Tamru et al. [53] explored issues related to the pricing and foreign exchange controls and Bastin and Matteucci [45] explored the challenges and opportunities related to financial services for coffee farmers. Other researchers have also focused on the value chain analysis of coffee. For instance, Beshah et al. [54] conducted a quality and value chain analysis of the Ethiopian coffee supply chain, while Minten et al. [50] explored the Ethiopian coffee value chain and identified the drivers and constraints coffee producers face. Mitiku et al. [55] focused on coffee certification in a comparison of the different coffee certification schemes currently operating in Ethiopia, Schuit et al. [56] focused specifically on Ethiopian specialty coffee and explored its potential for improving the income of the actors involved and Georgise and Mindaye [46] explored existing warehouse and inventory management practices in the Ethiopian coffee supply chain by conducting a case study on the Sidama coffee-growing region. However, studies exploring the digital traceability capability of the Ethiopian coffee supply chain are still lacking.

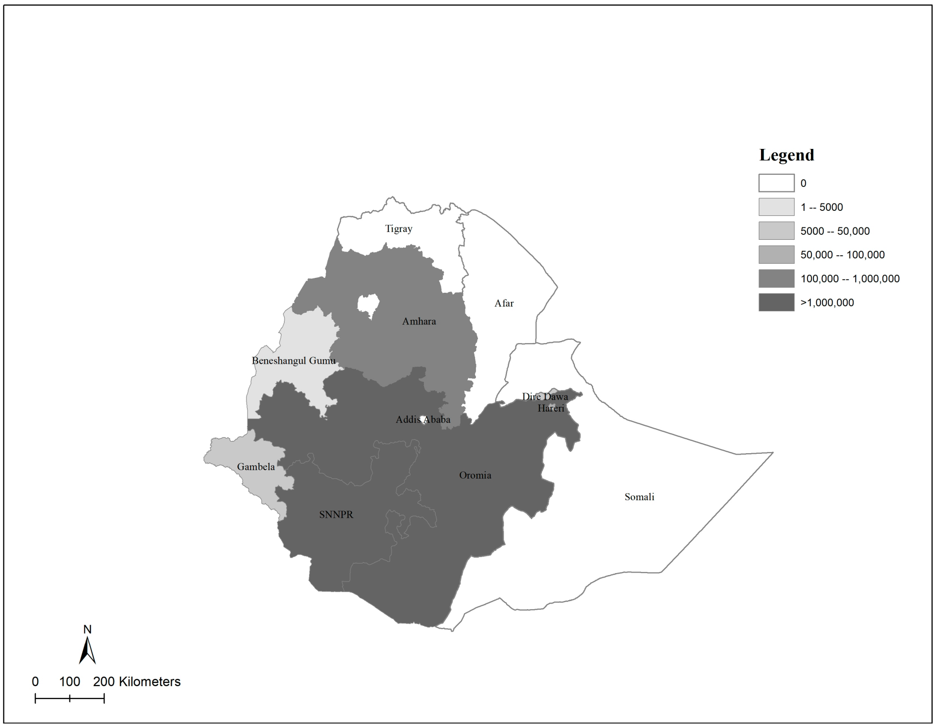

Figure 2. Coffee production in quintals in the different regions of Ethiopia in 2021 (Source: CSA [57]).

5. Results

5.1. Smallholder Farmers

The results of the logistics audit indicated that the eight smallholder farmers interviewed marketed their coffee through unions or private local traders. These smallholder famers have access to market information regarding coffee prices through announcements or meetings conducted between the farmers and the cooperatives, although some mentioned that their main source of information was word of mouth.

Regarding communication with other stakeholders, the smallholder farmers stated their preferred means of communication was via telephone, although some mentioned conducting in-person meetings.

To transport the harvested coffee beans, animal-based transportation systems predominated. However, two of the smallholder farmers reported using motorcycles for transporting the harvested coffee beans to collection points.

5.2. Exporters

The thirty exporters interviewed sourced their coffee beans from different regions of Ethiopia. The common destination countries for their coffee include Germany, the U.S.A., Japan and Saudi Arabia. Of the 30 exporters interviewed, 12 owned commercial farms, while the remaining sourced their coffee beans from smallholder farmers, cooperatives or local traders. These exporters had better access to market information as they relied on both local and international coffee trade prices. Regarding communication with other stakeholders found in the supply chain, they used mobile phones as well as internet-based communications such as emails. This indicates that the penetration of digital technologies improves downstream of the supply chain.

For transportation, exporters used trucks of varying sizes, including medium-sized and large trucks. However, some reported using hand carts and small pickup trucks when the transportation distance was short or the volume to be transported was low.

Out of the thirty exporters interviewed, only one stated the use of barcodes in their warehouse to ensure traceability. The others either had no traceability system at all or relied on manual methods such as paper-based documentation to ensure traceability in their supply chains. However, the system they utilised was internal and was not integrated with other stakeholders in the supply chain.

5.3. Transportation Companies

The transportation companies are responsible for transporting coffee beans from various regions in Ethiopia to Addis Ababa, where the quality of the coffee beans is controlled before export, or from Addis Ababa to the port of Djibouti. All ten transportation companies interviewed stated that they used mobile telephones for communication between truck owners, drivers and clients.

Regarding the use of digital technologies, only two out of the ten transportation companies interviewed used GPS trackers on their trucks. However, six of the transportation companies expressed a desire to implement the technology on their trucks in the future.

Transporting coffee from different parts of Ethiopia to Addis Ababa and from Addis Ababa to the port of Djibouti faces challenges. These include security problems, poor transportation infrastructure and theft.

6. Discussion

6.1. Current State of Traceability in Ethiopia

Traceability has become an essential practice today, as both coffee buyers and consumers are eager to know the origin of their coffee, the processing methods used, the transportation and storage conditions and the sustainability practices in place. According to a survey of 150 senior supply chain leaders by Saenz et al. [58], executives viewed traceability as extremely important. This is because traceability provides organisations with the means to enhance the safety, quality and sustainability of the products they sell [27].

The logistics audit revealed that all the stakeholders in the coffee supply chain had access to mobile telephone services, although those located upstream, including smallholder farmers, had limited internet access. This limited internet penetration in rural regions is attributed to the lack of a well-established internet infrastructure [36]. This is also the case for Ethiopia, where internet and mobile phone penetration in rural areas remains low [59].

A study by Arslan et al. [60] indicated that a key approach for improving the productivity of smallholder producers in Uganda was enhancing information transmission among smallholder producers and other stakeholders in the supply chain. In terms of information and communication technologies (ICTs), Ethiopia ranked 162nd, Uganda 133rd, Rwanda 134th and Burundi 161st out of 166 economies [61]. This shows that low-income countries are lagging behind in terms of technology readiness. This explains the low adoption rates of digital traceability technologies from low-income countries. However, efforts should be undertaken so that the supply chains originating from low-income countries improve, helping them regain their competitive advantage [61].

The logistics audit conducted in this study revealed that most exporters used paper-based systems for ensuring traceability. The prevalence of paper-based traceability systems is also common in rural areas where most smallholder farmers are IT illiterate. According to Setboonsarng et al. [7], the low IT literacy level of farmers in rural areas should not inhibit the implementation of a traceability system, as farmers could report their information on paper, and then their cooperatives or other stakeholders in the supply chain could record the information digitally.

For both exporters and transportation companies, the usage of location tracking devices such as GPSs is limited. Given the frequency for the occurrence of theft, GPSs could be implemented by exporters and truck owners. GPSs have been used widely for fleet management to monitor and manage assets [62]. Hopkins and Hawking [63] also indicate that the management of fleets to ensure the security of trucks can be enhanced by utilising sensors on both the driver and cargo compartment of the trucks.

6.2. Framework for Digital TS

Implementing a TS is a resource- and capital-intensive task [9]. However, a system of this kind can help stakeholders upstream of the supply chain have better access to both international and local markets enabling them to sell their products at a better price [5]. Thus, it is important to develop a framework that shows the different types of TS categorised on the basis of the technologies required so that it can apply not only to the Ethiopian coffee supply chain but also to supply chains in other low-income countries.

Based on the technology requirements and the works of Bravo et al. [9] and Dabbene et al. [64], this study made distinctions between centralised and distributed systems, as well as manually focused and digitalised systems. Based on these two dimensions, the TS framework was categorised into four levels: Level 1, Level 2, Level 3 and Level 4 (Figure 3).

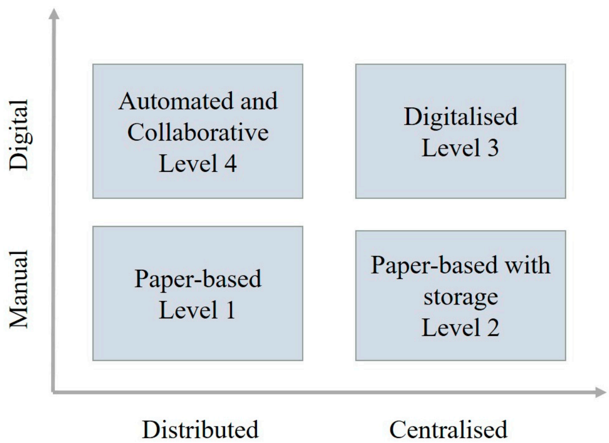

Figure 3. Categorisation of the four TSs.

Level 1: Level 1 is the simplest and most basic type of TS that stakeholders can adopt. In this type of TS, supply chain members collect information about coffee as it moves along the supply chain and record it on paper. Since advanced technologies such as IoT or GPS are not used at this level, stakeholders are not able to obtain moisture and temperature information during the processing, storage and transportation stages. Furthermore, stakeholders do not have access to real-time location information on their transportation trucks.

Level 2: The information stored in Level 2 traceability is the same as in Level 1, but the Level 2 TS stores the information collected in a central database. This type of TS avoids data being lost because the information from the supply chains is stored in a database. Additionally, it offers easy information access and coordination in the supply chain [5].

Level 3: The integration of supply chain information with digital technologies helps improve traceability along the supply chain [27]. With the incorporation of technologies in the Ethiopian coffee supply chain, information will flow smoothly across the supply chain. Additionally, the incorporation of technologies in the supply chain can enhance communication exchange, advance product flow and improve production and processing. Therefore, in Level 3 of the TS, recording of traceability information is digitised. Supply chain members can adopt technologies such as barcodes/QR codes and the information collected from these devices can then be transferred to a central database so that it can also be accessed by other authorised supply chain members. Stakeholders in Level 3 can also obtain location information for their transportation activities using GPS.

Level 4: Lastly, in the final level of the TS, i.e., fully digitalised TS, technologies such as barcodes/QR codes and IoT devices can be integrated with blockchain. Real-time location information can also be obtained with the incorporation of GPSs in trucks.

6.3. Challenges of Implementing TSs in Ethiopia and Other Low-Income Countries

The implementation of TSs by firms in low-income countries such as Ethiopia faces various challenges due to the complex structure of the supply chain, the involvement of a large number of stakeholders and the huge financial deviation that exists among stakeholders along the chain. TSs should be affordable to all stakeholders along the supply chain. However, the implementation of digital technologies, including blockchain, upstream of the supply chain, where farmers are mostly involved, is challenging, as 95% of the farmers in Ethiopia are smallholder farmers [44]. This is also true for other coffee-producing low-income countries, such as Rwanda, where coffee production is dominated by smallholder farmers [65].

For new technologies to be gauged as successful following their implementation, they should reduce costs, decrease risks, save time and increase transparency [3]. Tadesse et al. [66] also stated that the accessibility of the technologies, policies and the presence of the appropriate skills are all factors that should be considered when stakeholders in low-income countries adopt digital technologies. The challenges for the different TSs depicted in Figure 3 are presented in Table 1.

Table 1. The challenges for each level of traceability.

Levels	Technology Used	Challenges	Reference
Level 1	Manual recording	Data input inaccuracy Time-consuming to input data	[15] [7]
Level 2	Manual recording Central database	Data input inaccuracy Time-consuming to input data Added cost for investing in hardware, software and computers	[67] [7] [7]
Level 3	Barcodes/QR codes GPS Central database	Affordability Lack of awareness Shortage of skilled labour Resistance from supply chain members	[7,15,16,23,68] [7] [7] [16]
Level 4	Barcodes/QR codes GPS IoT Blockchain	Affordability Accessibility Lack of awareness Resistance from supply chain members Lack of adequate infrastructure Shortage of skilled labour Lack of policies	[13,69] [69] [69] [15,69–71] [15] [69] [15,35,71]

One of the main challenges stakeholders face, especially those located upstream of the supply chain, when deciding to adopt a full TS is affordability [24]. This is especially true for digital traceability solutions (Level 3 and Level 4). The implementation of blockchain in particular requires considerable investment [13,29,71] due to the infrastructural requirements of the technology. To make the digital TS mentioned in Figure 3 affordable, Demestichas et al. [3] recommend implementing the technologies step by step, with certain members of the supply chain adopting the technologies. The feasibility of the digital TS can then be studied to check if the recommended TS is successful before extending it to other stages of the supply chain.

The implementation of TSs requires all members of the supply chain to be aware of the importance of such systems. Studies have shown that one of the most significant barriers to the adoption of technologies is a lack of awareness [36,69]. Thus, awareness campaigns on the potential benefits of using traceability are important [16]. Cooperatives serve as a link between smallholder farmers and governmental and non-governmental organisations [65]. Hence, training and capacity-building programs that are catered to create awareness and improve the knowledge of farmers can be conducted through the cooperatives.

One of the challenges in implementing digital TSs is the resistance of some supply chain members to their adoption. Manos and Manikas [16] stated that there was resistance from cooperatives to invest in digital technologies to attain advanced TSs. This is especially true if the already existing paper-based TS is working perfectly [29].

Developing a full TS requires collaboration from all the supply chain members found in the chain [58]. However, supply chain members might not be willing to share their information on a common platform due to a lack of trust among them [71]. Wang et al. [29] also stated that some supply chain members might be resistant to this high level of supply chain transparency and the influence the technology has on intermediaries (brokers) in low-income countries.

6.4. Implications

6.4.1. Managerial Implications

Implementing a digital TS in the Ethiopian coffee supply chain can yield significant benefits for all stakeholders involved, from producers to exporters.

From the producers' perspective, enhanced traceability can provide them with accurate and timely information about the current selling prices of coffee. This access to real-time market data empowers them to make informed decisions, ensuring they receive fair compensation for their products. Additionally, such a system can facilitate participation in fair trade schemes, allowing producers to gain recognition and financial benefits for adhering to sustainable and ethical farming practices.

For exporters and international traders, a digital TS offers detailed information into the sustainability practices employed at the production level. This transparency ensures that they can verify the quality and grade of the coffee they are purchasing, which is crucial for maintaining high standards and meeting consumer expectations. Moreover, the ability to trace the coffee through every stage of the supply chain enhances their ability to market the product as sustainable and ethically sourced, potentially commanding higher prices in the market.

Furthermore, the improved transparency and monitoring capabilities provided by a digital traceability system can significantly reduce the risk of fraud and theft, which are common challenges in the transportation phase of the supply chain. By tracking the coffee in real time, stakeholders can ensure that the product reaches its destination without tampering, thus maintaining its quality and authenticity. This increased security not only protects the financial interests of all stakeholders involved but also builds greater trust and reliability in the supply chain.

6.4.2. Policy Implications

Traceability is an essential requirement for food commodities, ensuring that the journey of a product from farm to table is transparent and monitored. Digital technologies are pivotal in achieving this level of traceability within supply chains. Therefore, robust regulatory frameworks are necessary to guarantee that high-quality products are consumed both locally and internationally.

The implementation of digital traceability systems ensures transparency and monitoring throughout supply chains. This transparency can serve as a critical tool for governmental bodies to conduct quality checks and significantly reduce the incidence of fraud. By having a clear, traceable path of food products, governments can more effectively oversee and maintain food safety standards, benefiting consumers and enhancing the overall integrity of the food supply chain.

Yadav et al. [71] highlighted that a lack of proper government regulation is one of the primary barriers to adopting digital technologies. Government intervention is necessary not only to enhance internet accessibility but also to improve other infrastructural requirements that boost efficiency in supply chains [35]. By formulating appropriate policies, the government can facilitate the adoption and implementation of digital technologies [72]. Additionally, the government is responsible for disseminating knowledge about food quality and safety and creating standards that align with international traceability requirements [16,73]. This helps to ensure that all stakeholders in the supply chain understand the importance and benefits of a digital traceability system.

Moreover, the government can play a pivotal role in raising awareness about the necessity of digital traceability systems among all stakeholders involved in the supply chain [69]. Aragie [74] noted that governmental policies in the coffee sector have a significant impact on productivity, especially since bureaucratic export processes can hinder efficiency in low-income countries [75]. A study by Kangile et al. [76] also indicated that inefficient government regulations could impede the productivity of coffee growers and limit their access to international markets.

7. Conclusions

Traceability can be improved in supply chains with the adoption of digital technologies. The case study conducted on the Ethiopian coffee supply chain showed that the level of implementation of digital technologies along the supply chain was low. However, the usage and implementation of technologies seemed to improve as coffee moved downstream in the supply chain.

With the usage of traceability technologies, stakeholders can improve their product's visibility and increase their competitive advantage on the global market. In this study, a framework for different TS was developed. The developed TS ranged from a manual system to a fully digitalised system. Although implementing fully digitalised TS in Ethiopia and other low-income countries could present a challenge, firms in the country might benefit by first adopting a TS that is less digitalised. This would improve the reliability of the products being exported by the country, making it competitive on the international market. Thus, this research proposed a framework for a four-level digital traceability solution, where the technology requirements increase as the levels advance.

The implementation of digital TS faces a number of challenges in low-income countries, one of which is affordability. Other challenges to implementation include lack of adequate infrastructure and poor accessibility to new technologies. This can be solved by interventions from private, governmental and non-governmental bodies. Capacity-building programmes are also vital to create awareness of the technologies and provide training on their use.

The level of digital traceability considered in this study focuses on Ethiopia as a case study. Although the structure of the coffee supply chain in other low-income countries might share similarities, it is essential for future researchers to identify the key stakeholders specific to those supply chains. This will enable the development of digital traceability frameworks that are tailored to the unique needs and conditions of their respective supply chains.

In this research, a framework for digital TSs was developed specifically for the Ethiopian coffee supply chain. However, its implementation and applicability have not yet been tested in real-world scenarios. Therefore, future researchers could undertake the task of testing the feasibility and practicality of this developed framework within the Ethiopian context. Moreover, the framework's applicability should be explored beyond Ethiopia. Researchers could test the feasibility and suitability of the digital TS framework in other low-income countries with similar supply chain structures. This comparative analysis could provide valuable insights into the adaptability of the framework across different geographical and economic contexts.

Additionally, future researchers could focus on evaluating the broader impacts of implementing digital TSs. This includes assessing the economic, social and environmental benefits for all stakeholders involved in the supply chain. Understanding these impacts will provide a comprehensive view of the value and effectiveness of digital traceability frameworks.

Author Contributions: Conceptualization, M.D.T. and G.G.; methodology, M.D.T.; writing—original draft preparation, M.D.T.; writing—review and editing, G.G., D.L. and L.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Netherlands Initiative for Capacity Development in Higher Education (NICHE) under the CBP-Ethiolog project (project No. NICHE-ETH-285).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors would like to acknowledge the project funders as well as the participants of the survey.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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