Beyond compliance:
Towards proactive Due Diligence
Leveraging Digitalisation for Visible and Responsible Fresh Produce Supply Chains

position paper

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1 Setting the stage

Few other industry sectors occupy such an interesting place at the intersection of regulation, sustainability and supply volatility as agricultural supply chains. From crops suffering from climate change to demanding European consumers, fresh produce is readily available at discount grocery chains to high end micro markets. Produce is sourced at competitive prices all year round from unknown middle wholesalers, leaving farmers unseen by consumers. As European regulators strengthen quality and safety standards for consumers, certifying bodies and new legislation (such as CSRDDD) are seeking to improve economic and environmental conditions for upstream producers. This highlights the pressing demand for systemic change that should have been implemented long ago.

There is increasing demand for transparency, sustainability and accountability in globally sourced fresh produce (Tan et al. 2023). Amidst varying regulatory frameworks in cross-border trading of fresh produce and heightened risk of fraud, the traditional paradigm of compliance-based documentation needs to be reformed. A transformative shift is needed from mere compliance to proactive due diligence (Schilling-Vacaflor and Gustafsson, 2024). This transition demands for robust digital infrastructure which can ensure that process of food certification is traceable, transparent and interoperable within trading partners.

1.1 Goals and Motivation

Digitalisation has long been seen as the key to improving supply chain sustainability (Sodhi and Tang, 2019). Whether it is the promises of blockchain in tracing cocoa to reduce child labour or AI to make processes more efficient and reduce product waste, technology solutions rarely provide silver bullets. Sample problems are that the implementation of technology is cumbersome and expensive, and that it is difficult to determine how effective they are on the scale required to make a difference (Heldt and Pikuleva, 2024). Literature shows that systemic challenges in supply chains cannot be solved by a single technology or a single firm acting alone. It requires multiple stakeholders throughout the supply chain to provide input for appropriate design and implementation of a technology. There may be many solutions that can work together to form a comprehensive solution in providing visibility of upstream producers to buyers, creating value for each supply chain tier and improving overall agricultural practices.

Digital solutions usually aim to leverage technologies to fundamentally enhance the visibility, accountability, and responsiveness of global Fresh Produce Supply Chains (FPSCs). The implementation of digital solutions—such as AI, blockchain, interoperable traceability platforms,

digital certifications, and automated compliance tools—is seen as an enabler of systemic change that goes beyond technology implementation.

By making critical compliance and sustainability data accessible, verifiable, and actionable across chain actors, these technologies are believed to support due diligence, mitigate risks, and foster trust. Over time, this enhanced transparency is expected to empower stakeholders—especially upstream producers—to participate more equitably, while enabling regulators, certifiers, and buyers to fulfil their mandates more effectively. The long-term impact is a shift toward more resilient, just, and sustainable trade networks where digital infrastructures support shared responsibility and continuous improvement.

The overarching research objective moving forward concerns how to co-develop a digital solution suited for specific supply chain use cases. Ultimately, we want the digital SCM solutions to reflect *people centred design,* where stakeholders are considered at each stage of development and implementation. To design an effective and *usable* solution, stakeholders must be centred throughout the process. This motivation combined with the literature review and stakeholder consultation has resulted in the following questions for further enquiry:

- What is the current status of digitalization in current trading practice of fresh produce and what is required to effectively include small and medium-sized companies (SME's)?
- Who are stakeholders involved in regulated certification processes and what are their needs, and what are issues?
- How should digital solutions be informed by supply chain complexity to improve visibility?

The following section 1.2 summarizes current visibility in FPSCs. General stakeholder groups are introduced, including sourcing supply partners, business operators and institutions, especially official controllers. Then, typologies of the issues and needs for global FPSCs are considered. This includes addressing the complexities of both compliance and voluntary certification documents. Finally, digitalization, its current state in supply chain management and the role it can play in further development, ensuring compliance and quality assurance. Our goal is to understand the current context of supply chain visibility and the role specific digital tools can play in supporting both regulatory and voluntary supply chain management reporting.

1.2 Current (In)visibility and Challenges

Global FPSCs involve a complex web of internal and external stakeholders. Internally, these include producers, input suppliers, packers, exporters, and multinational retailers. Externally, the landscape encompasses regulators, certification bodies (public and private), logistic providers,

data service intermediaries, financial institutions, and civil society actors. Each plays a role in shaping both compliance behaviour and data visibility. Importantly, we refer to visibility as internal transparency between supply chain partners which includes product traceability, quality and process information key to managing sustainability in FPSCs (Schäfer, 2023). In contrast, (External) transparency refers to the availability of relevant (supply chain performance) information to external stakeholders such as consumers, investors, and regulators (Gardner et al., 2019). Supply chain visibility is also important for formal governance by making it easier for firms to meet regulatory reporting requirements.

Barriers to visibility occur in each facet of FPSCs:

- Operational (e.g., inconsistent data formats, unreliable recordkeeping)
- Institutional (e.g., fragmented governance, overlapping certification demands)
- Technological (e.g., lack of digital infrastructure or access at source level)
- Economic (e.g., price pressures, low margins, limited investment capacity)
- Socio-political (e.g., power asymmetries, limited voice for producers)

These systems are inherently complex due to their multi-actor nature, cross-border regulation, and asynchronous flows of goods, data, and capital. The absence of harmonised data ecosystems exacerbates compliance risks and reduces agility. Furthermore, trust deficits between actors—often amplified by digital opacity—undermine collaboration and value co-creation.

Institutions such as trade ministries, food safety authorities, and international organisations (e.g., WTO, FAO) set the regulatory frameworks within which trade must operate. In parallel, certification schemes—ranging from voluntary sustainability standards (e.g., GLOBALG.A.P., Rainforest Alliance) to mandatory compliance regimes (e.g., EU Due Diligence, phytosanitary requirements)—serve as gatekeepers of market access and product legitimacy. These certifications often cover aspects such as product quality, food safety, environmental performance, and social conditions in the supply base.

International FPSCs are highly dynamic, often involving long-distance trade lanes from the Global South to consumer markets in Europe, North America, or East Asia. These supply chains are characterised by seasonality, perishability, and regulatory sensitivity, making accurate, real-time information crucial. Digital tools can enhance traceability, automate documentation, and reduce transaction costs—yet adoption is uneven and fragmented.

The emergence of due diligence regulations and global pressure for sustainable and ethical trade are placing fresh demands for proving the integrity, origin and safety of products. Digitalization of phytosanitary food certificates could serve as powerful foundation to meet these obligations. The need for digital transparency is further driven by rising consumer expectations, evolving ESG norms, and the tightening of due diligence regulations. Suppliers increasingly face

pressure to prove compliance not only with product standards, but also with broader social and environmental expectations. Data interoperability, certification verification, and chain-of-custody assurance have become central to trust-building in these systems.

In FPSCs broadly, shipment documentation is still mostly done on physical paper (Laget and Deuss, 2023). Traditional paper-based certification mechanisms limit visibility, which creates information bottlenecks and loopholes for fraud (Prashar et al. 2020):

Document tampering and fraud: Paper-based documents are often susceptible to manipulation, duplicate usage of same certificate for multiple consignments. Such malpractices do not undermine security concerns but also erode the trust of trading partners. Hence, digital traceability is required to verify the chain of custody.

Lack of real-time data sharing across borders: Currently, there is a shortage of a unified/interoperable system between the authorities dealing with the issuance of phytosanitary food certificates between the proposed tradelines. This fragmentation leads to manual re-entry of data and redundancy in verification checks. Visibility is therefore hard to reach, which leads to uncertainties, resilience risk, and waste created along the chains.

Systems must be designed for managing these different information types. While import documentation is regulated and standardized, any information sharing outside of the scope of regulatory compliance, such as for phytosanitary certification, is subject to industry discretion. Information being requested and subsequently shared via voluntary certificates (e.g., FairTrade) or corporate sustainability initiatives are not clearly defined and therefore more difficult to verify with basic AI or IoT enabled tools. While standard system design is suitable for managing required documentation, sustainability and due diligence information is not, and therefore would require customization to manage this voluntary information more effectively. To move from compliance to due diligence, effective systems must integrate design elements to manage both required and voluntary information types.

1.3 Role of Digitalisation

Technology can be a key enabler of sustainable supply chain management (SSCM) by making it easier and faster to share information between supply partners. Several types of technologies have been developed and applied for this purpose, notably blockchain for tracing source of origin and IoT for physical shipment tracking and lately Artificial Intelligence, especially Gen AI, for automated document handling, predictive analytics, risk detection, and intelligent decision-making across supply chains. However, digitalization is underutilized, with most processes requiring paper documents. Various technologies have been met with little widespread success

due to lack of accessibility and standardisation, high costs and low willingness to invest (Heldt and Pikuleva, 2024).

In our context of FPSCs, there are two key types of documentation that are the focus of digitizing: regulatory and voluntary. Regulatory documents include phytosanitary health certificates, point of origin, invoices, bills of lading, etc. Voluntary documentation refers to any sustainability information the buying firms may want to use in consumer advertising or to meet internal sustainability targets. These include certificates from external organizations, like FairTrade, or internal reporting metrics.

The technological advancement under portfolio of Industry 4.0 paradigm has widened scope of digitalization in effective management. Its integration with the supply chain activities improves traceability, while providing end-to-end visibility, which is required to improve the efficiency and governance of supply chains. Furthermore, it enables information sharing with a variety of external stakeholders, such as regulatory bodies that oversee foreign trading partners.

By making critical compliance and sustainability data accessible, verifiable, and actionable across chain actors, these technologies can support due diligence, mitigate risks, and foster trust. Over time, this enhanced transparency is expected to empower stakeholders—especially upstream producers—to participate more equitably, while enabling regulators, certifiers, and buyers to fulfil their mandates more effectively. The long-term impact is a shift toward more resilient, just, and sustainable trade networks where digital infrastructures support shared responsibility and continuous improvement. Hence, to improve the dimension of sustainability and make supply chains due diligent it is required to go beyond digitalizing phytosanitary food certificates used in import/export procedures for fresh produce (Samal and Jena 2025).

2 Finding a way forward

As discussed, visibility is low between agricultural producers and buyers. Various digital solutions have been developed for this purpose (e.g., digital platforms, either centralized or decentralized, using blockchain technology, for instance), yet widespread adoption remains low. Additionally, before technology can be used to share knowledge effectively between supply chain partners, we need to first understand who they are. In order to develop and implement a workable digital solution that enables FPSC visibility, multiple stakeholder (including upstream suppliers) involvement in the design stage is needed.

To do this, we explore two practical examples based on stakeholder input. The first explores what is needed to meet regulatory aspects of visibility: digital transfer of phytosanitary

certificates from the Netherlands to the UK. The second goes beyond what is needed to meet regulatory requirements towards due diligence: avocados produced in Kenya and shipped to the Netherlands via sea freight. Different approaches are taken to address the unique context of each example case. We explore how to address the specific challenges of achieving visibility with existing or proposed implementation of digital solutions. These are representative of the types of use cases that can be developed further in future research.

2.1 Regulatory Case: NL to UK

The Netherlands and United Kingdom trade is among busiest tradeline in terms of volume quantity being exported from Netherlands. This exporting region is acting as a key partner which governs sourcing from other European Union regions and UK as a consumer. It is being estimated that Netherlands handles roughly 20% of Europe's fresh produce imports and 28% of intra-EU fresh produce exports (CBI, 2022). In 2018, some of the major export commodities to the UK from Netherlands were tomatoes (€279m), sweet peppers (€203m), cucumbers (€102m), onions (€74m) and avocados (€50m) (LPS, 2019).

Post-Brexit, export of fresh produce from Netherlands to UK faces challenges due to usage of physical phytosanitary certificates. With Brexit, the UK is now considered a third country to the European Union, requiring a secondary phytosanitary and health certificate check for plant-based goods at its border (Cheptea et al. 2021). This has put an additional burden on the supply chain operations associated with fresh produce, in terms of documentation, delayed inspection and clearances. It impacts the sustainability and governance associated with the fresh produce supply chain.

2.1.1 Trade Lane Overview and Challenges

Post-Brexit, increased regulatory burden on fresh produce trade from Netherlands to the UK has also increased the complexity and frequency of border checks (Jagtap et al. 2024), determining the need of fast and reliable phytosanitary certifications. These inefficiencies not only increase costs and risk associated with import-export of fresh produce but also obstruct the ability of regulatory bodies and business to exercise proactive due diligence over quality, origin and compliance of produce. These phytosanitary certificates are vital and important documents to verify that agricultural exports meet the importing country's plant health requirement (Montilon et al. 2023).

Digitalization of these certificates is not just a technical upgrade, it is strategically important for building efficient, resilient and transparent import-export procedures.

Phytosanitary certificates are signed, printed and physically carried or scanned to accompany with the shipments. This is prone to errors and delays and hampers the ability of border authorities to verify their authenticity. In FPSCs, operational delays of a few hours can result in spoilage and rejection of consignments.

A key challenge with the UK tradeline persist due to delay in documentation required for its export from Netherlands. It is due to inconsistencies persisting within the documentation arriving from the third countries. Eventually, UK often receives re-exported fresh produce, becoming third or fourth-level recipient of phytosanitary certificates and customs documentation, which are paper-based and prone to susceptibilities. Digitalisation of the phytosanitary certificates would enable faster, more secure and traceable information exchange across borders. This significantly, reduces the inspection delays and improves the supply chain efficiency.

2.1.2 Transition towards digital phytosanitary certificates

Currently, the visibility of the process of issuing phytosanitary certificate is in response to regulatory checks rather than the result of a continuous and integrated improvement process. This limited visibility impacts the wide range of stakeholders; exporters/importers face delays due to documentation errors, certifying authority struggle with fraud detection, and consumer remains unaware of provenance of their food. To address these challenges and reduce the delays associated with fresh produce in import/export procedures owing to the exchange of phytosanitary food certificates, digitalization is required. In the era of industry 4.0 many technologies like Artificial Intelligence (AI), blockchain and interoperable data, platforms can be leveraged for digitalization of phytosanitary food certificates and other documents associated with trading of fresh produce.

Digitalization of the phytosanitary food certificates makes FPSCs due diligence advancing from existing compliance based. By transitioning from paper-based to digital formats, these certificates can become part of an interoperable, tamper-proof system which enhances the traceability, integrity and accountability of fresh produce shipments. A digital certificate can be instantly shared, verified and updated across all stakeholders from regulatory bodies to customs, trades and retailers which eliminates bottlenecks, reduces human errors and imperfection in documentation. It ensures real-time transparency in the process of issuing phytosanitary standards, not just at point of inspection, thereby shifting the emphasis from one-time compliance to ongoing responsibility. Leveraging the potential of digital phytosanitary food certificates in tradelines triggers a proactive approach in a fresh produce supply chain, enabling actors to

demonstrate adherence to environmental and ethical standards. Hence, digital phytosanitary certificate intends to make these tradelines operations efficient, transparent and due diligent.

2.2 Due Diligence Case: Kenyan Avocados

Because due diligence requires going beyond a first-tier supplier (e.g., wholesaler), this section is broader in scope. Based on Dutch produce industry input, avocados were identified as a particular product of interest. Therefore, we use the example of fresh avocados from Kenya via sea freight to highlight various stakeholders and potential applications of digital solutions. We look at the whole supply chain to identify stakeholders and processes where information sharing is needed to address due diligence concerns beyond what is regulatorily required. This involves supply chain mapping to visualize the relationships between tiers and what developers may need to consider when designing an effective digital solution.

2.2.1 Contextual overview

Fresh produce comes with a unique set of challenges due to high regulatory standards, low profit margins and high perishability. Avocados from Kenya present an interesting opportunity for European import due to their high consumer demand, long travel distance and highly perishable nature. Improving access to markets for smallholders would increase avocado volumes to not only reduce reliance on more expensive avocados from e.g., Peru, but also manage demand-supply risks (OECD and FAO, 2021). The Kenyan avocado industry has been growing and attracting more investment (Kariuki, 2023), making it a high growth opportunity for Dutch import interests. Kenyan avocados can also be grown with fewer pesticides/fertilizers and less strain on irrigation systems compared to South America (Fit for Market SPS and NExT Kenya programmes, 2023), satisfying market desirability for sustainability.

Kenya is a high-volume exporter of fresh produce to the Netherlands and other European countries via reexport through the Rotterdam port. Kenya has a well-established export market to Europe, making up 58% of EU vegetable imports (Match Maker Associates, 2017). Kenya is considered a ‘green’ lane country with special trade agreements with the EU to make trade easier. Kenya is also a major intermediary hub for produce from neighboring countries such as Uganda, Tanzania and Ethiopia to the EU (Birachi et al., 2023). TradeMark Africa is an innovative partner with Docklab in developing better systems to ease trade between Africa and the Netherlands. Kenya has a strong trade position with advanced information management capabilities and highly digitalized port authority.

The 2023 Economic Partnership Agreement (EPA) with Kenya codified Kenya's trade relationship with the EU (European Commission, 2024). It guarantees duty-free access to the EU market and upon implementation, will include trade and sustainable development commitments (European Commission, n.d.b). Kenya has already been a reliable trading partner with the EU, but this agreement will expand trade opportunities further. Increased volumes will require more efficient government-government customs procedures. Not only will high importing EU countries, like the Netherlands, need to continue developing more efficient customs procedures with Kenya, but as more East African Countries (EAC) ratify the EPA, other countries as well.

Challenges and Opportunities

To understand potential pain points regarding import from Kenya, formal notices were looked at on the RASFF window. Keeping track of notices is important because it can help identify specific areas that can be targeted for improvement. If products receive too many notices, exporting countries may lose their 'green flag' status and be subjected to higher import scrutiny. Though only two notices were given to Kenyan avocados between 2020 and 2025, both cases cited unacceptable levels of chloorpyrifos pesticide residue in 2022 and 2023. Though Kenyan avocados reportedly use fewer pesticides relative to other crops, details of pesticide use would be useful to have documented into a digital system at the producer level. This is just one example of voluntary information that could help both avocado producers and importers increase the success of avocado trade.

There is also a gap between large scale avocado production and access to the EU market. Kenya is one of the top avocado producers globally, but this is not translated to exportable goods. Only 15-20% of total avocado produced in Kenya are slated for the EU market (larger operations; Hass variety), and not all of it will make the grade, leaving only about 10% for export (Fit for Market SPS and NExT Kenya programmes, 2023). There is great value opportunity wasted when not bridging the gap to smallholder farmers. Ensuring accurate and timely issuance of phytosanitary certificates is a key difficulty involving smallholder farmers, which leads to shipment delays, rejection or repetitive inspections (Alford et al. 2024).

According to stakeholder input, there are specific control risks with data entry and transfer. There could be discrepancies depending on whether the control checks were done by an inspection agent with a tablet or paper clipboard; conflicting PDF layout formats of the inspection reports, customs and consignment documents can cause disruptions when crossing borders. Government to government systems require standardization of customs paperwork to ensure quality, but paper documentation required by current policies is more vulnerable to human error (Laget and Deuss, 2023). Simple mistakes when transposing data can hold up goods

unnecessarily, while transferring a single digital document would reduce human inputs (Port of Rotterdam Authority, 2024).

This would appear to be a good case for digitalizing the customs process. This has been a driving factor of the Kenyan Port Authority working with IOTA and TWIN to digitalize trade documents to ease exports to the EU. In a working context, there are blockchain application opportunities via IOTA; where unique customs – customs consignment codes can ensure reliability/consistency of documentation for product shipments. Since TWIN is decentralized, supply-side partners can access the system via their own node/digital ID. This would in theory suit both supply and demand side needs for an effective and efficient system for coordinating supply chain information, which can start with digitizing documentation.

However, a key barrier is that there is a lack of acceptance of digital documents from Kenya. Despite these efforts, there are still trust and governance issues between parties. EU regulations are quite stringent and can be difficult to keep up with, especially when there are changes and slightly different interpretations by country. There is a 'wet stamp' bias by EU importing countries that add an extra layer of complexity when evaluating fresh produce certificates/documentation coming in from Kenya. This then becomes a political issue, not a technical one.

2.2.2 Supply Chain Mapping: People, processes and product

Stakeholder groups can be summarized as the product/information source, governing agencies and importers/distributors. These are the three broad stakeholder groups that would need to be considered for a pilot: Kenyan farmers/exporting firms, port authorities and government customs agencies (Kenyan-Dutch) and Dutch purchasing firms.

The Kenyan government and industry groups have also invested heavily in digitalization of global trade. The state agency KenTrade facilitates and manages the digital trade platform, InfoTradeKenya, with the goal of simplifying and automating global trade. Detailed documentation and processes required for exporting to the EU is easily available via this platform. TradeMark East Africa is also working with IOTA and regional governments to facilitate reliable and efficient information flows between traders and global markets.

GroentenFruitHuis (GFH) represents organizations that make up 80% of the Dutch produce industry, with roughly 40 importing member organizations (GroentenFruitHuis, n.d.). They are interested in efficiency, quality assurance and sustainability (GroentenFruitHuis, n.d.). Other digital solutions have been piloted with industry partners such as DigiTAAL which is working towards international standardization of data.

To illustrate the current state of the avocado supply chain from Kenya to the Netherlands, a map was developed based on literature review and stakeholder input. The following Figure __ includes:

- Physical product flow
- Information flow
- Stakeholders and supply chain actors
- System processing points

This map is an example, focusing on the value chain of larger, vertically integrated exporting firms who contract with small-medium avocado growers.

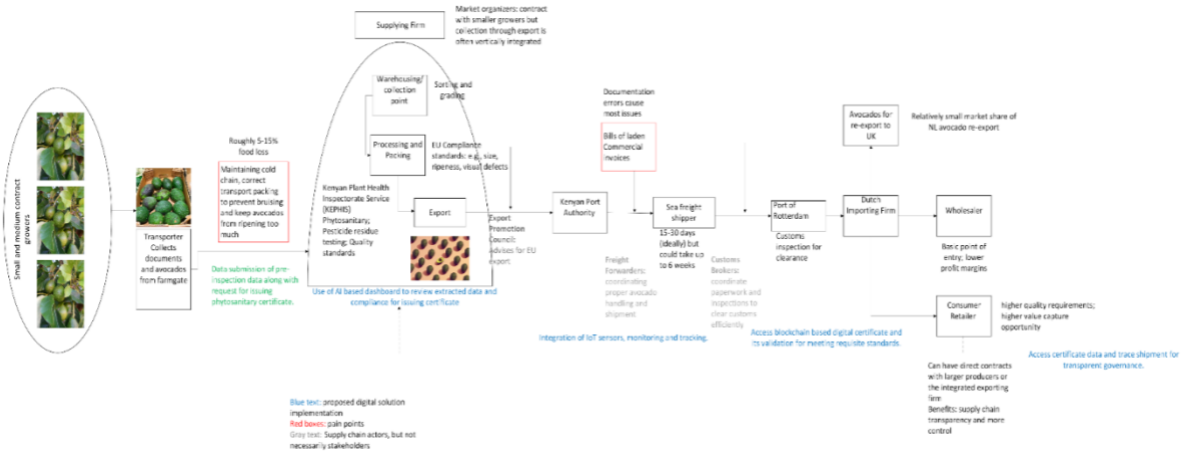

Figure 1: Specific pieces of information which avocados go through to become successfully exported from Kenya to the Netherlands alongside KEPHIS (Kenyan phytosanitary certification) are: Name and address of producer, Brand or trademark, Country of origin, Type of avocado and grade, Storage instructions and temperature requirements, Gross weight and number of avocados per carton, Shelf life, Harvest year and packing date.

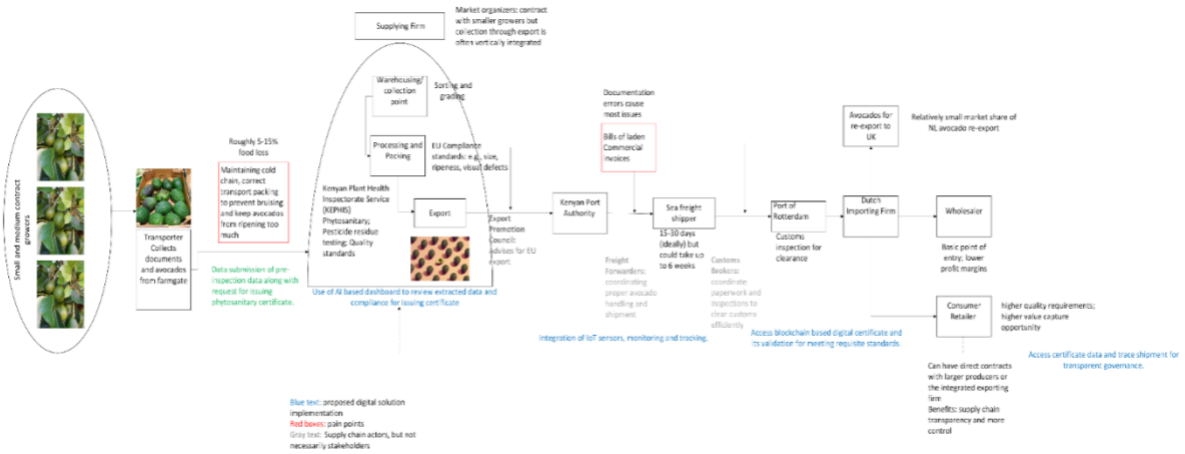

Figure 1 maps out the general overview process of avocados being produced at the farm level to being distributed by Dutch wholesalers and retailers. Currently, there lacks a clear documentation chain that can be generalized for avocado supply chains. The consistency and amount of information being shared largely depends on the scale of production and the type of buying firm. Though invoices and phytosanitary certificates are fairly standardized, there are still

variations. And this becomes far more complex when voluntary information sharing (e.g., sustainability related) enters the equation. Therefore, only general problem areas are identified in Figure 4: (red text) which could be addressed with digital solutions discussed in Part 1 (green and blue text). This simply provides an overview of the supply chain stages where digital interventions could be useful for sharing information between partners.

2.2.3 Example of digital solutions

Reflecting on the earlier discussion of potential digital solutions (Section 2.1.2), specific intervention points were explored further in the context of avocado supply chain mapping. These digital solutions include blockchain, IoT, AI and smart contracts. Figure 2 summarises the architecture layers of the application digital solutions.

Digitalization of the phytosanitary food certificates involves the system, integration comprising of the blend of blockchain, AI and IoT based technologies. It refers to the independent role of every technology which drives the common outcome resulting in the digitalization of certificates. It can be understood from the figure _ which details system layer and functional design of proposed architecture of digital phytosanitary certificates for the proposed tradelines.

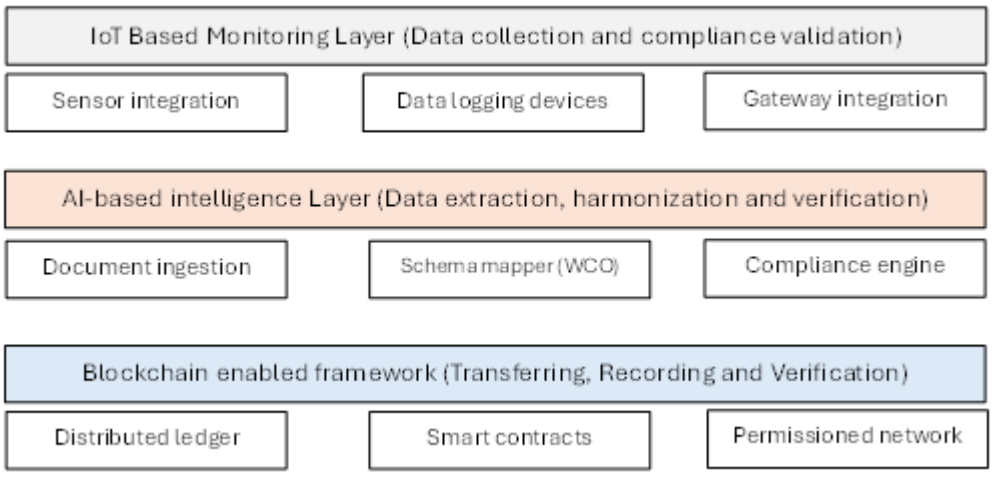

Figure 2: Proposed system integration for digitalization of phytosanitary certificates

Layer 1: IoT based data monitoring layer

It is entry to the point to the information pertinent with the issuance of digital phytosanitary food certificates issuance. It is intended to capture the real-time environmental data and shipment traceability to meet the phytosanitary standards. This technology comprises of components

having sensors integration to capture real-time data inputs, data logging devices to transit data to cloud and gateway integration for sharing aggregated data with certificate management system in real-time.

Layer 2: AI-based intelligence layer

This layer is purposed to process and validate phytosanitary certificates from diversified formats/sources as per requirement of import/export partners. It comprises of a component, which accepts certificates in various file formats (online/offline), and which extracts key fields and maps it with the requisite standardized data format issued by WCO. Furthermore, it also checks for compliance with the regulatory rules for fulfilment of requirement to issue a digital phytosanitary certificate.

Layer 3: Blockchain-enabled trust framework

It is required for sharing and providing verifiable mechanisms for phytosanitary certificate records. This technology enables inter-country verification of digital version of certificates and records outcomes based upon IoT and AI integration. It comprises of distributed ledger to store information, smart contracting mechanism to improve autonomy of verification and validation.

To illustrate an example of how digital solutions could be implemented in the avocado supply chain, Figure 3 proposes potential digital intervention points. Blue boxes denote stakeholder users of a digital solution implementation. The orange boxes denote examples of digital tool applications. Green boxes are the types of information being shared.

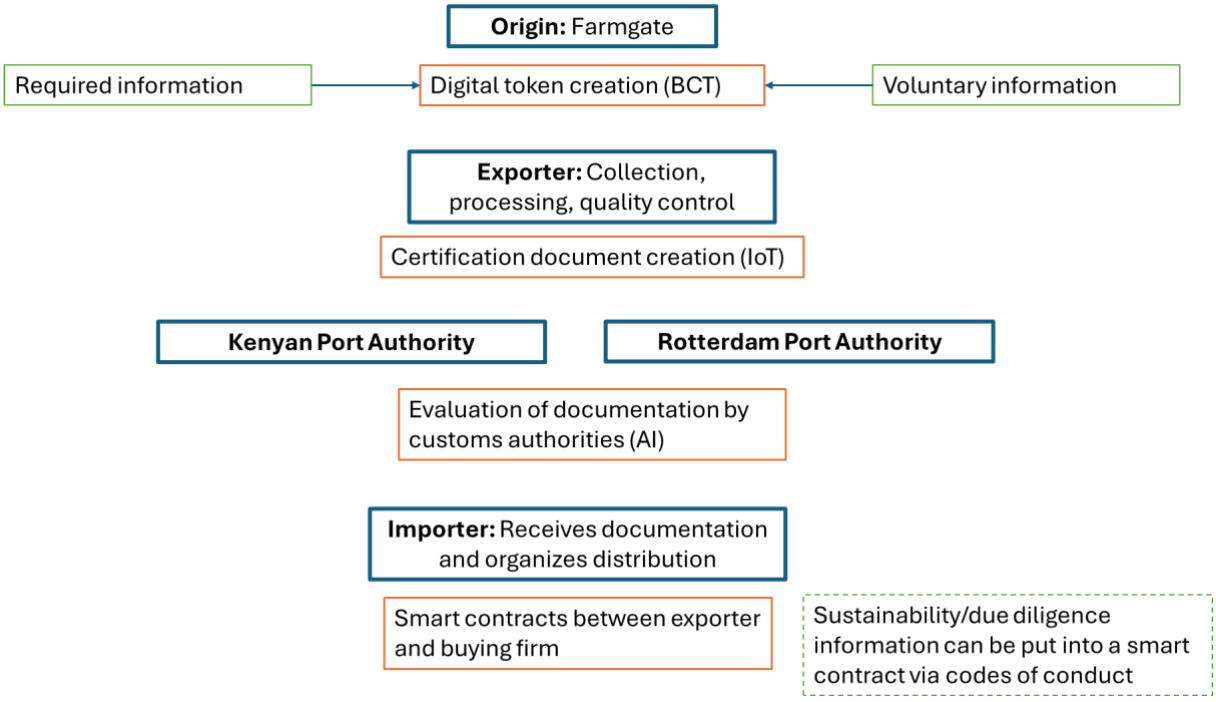

Figure 3: Proposed digital intervention points

3 Future Research Pathways

This section builds on the issues first outlined in Chapter 1. There is an **opportunity** to solve current issues through digitalization:

- Improve current paper-based processes;
- Standardise data sharing across supply chain, ensuring smoother reporting (e.g. for CSRD or CSDDD);
- Make supply chains more efficient by streamlining data management.

To do so, we first formulate questions, which draw from the research conducted when developing case examples in Chapter 2. Next, a research approach is outlined that puts stakeholders at the center of any digital solution implementation process. Finally, various solutions are discussed in further detail; including functionality, requirements and what is needed to overcome barriers and reap benefits.

3.1 Questions

Stakeholder Engagement

Digitization can provide benefits for a variety of stakeholder groups, but it faces unique barriers. On the supplier side, widespread access to digital solutions has the potential to reduce product waste, increase market efficiency, level inequality for farmers, and capture value. The current lack of visibility means it is more difficult to identify and target smallholders for implementation.

In general, adoption is low amongst smaller supply chain actors, such as smallholder farmers and lower volume traders. These smaller actors have basic technology like mobile phones, but access to the internet is low. This is a significant barrier to farm-gate transfer of digital documents, since this would require internet access to be available in rural farming communities. Even amongst larger farms, digital system adoption is low, because exporting to the EU requires physical documentation regardless. Overall, coordination between supply partners is low.

RQ1: What is the current status of digitalization and what is required to effectively include SME's?

This questions builds from the description of the current situation while putting SME's in focus.

Data Governance

On the buyer side, tracking and tracing achieve sustainability goals while simultaneously achieving effective supply chain coordination goals that focus on risk management (Parmigiani et al., 2011). When there are quality issues in one region, brought on by flooding or drought, for example, shipments containing products from these specific regions could be isolated for further inspection instead of checking every shipment. Digitalization could also be used to address CSRDDD regulations regarding environmental and social information reporting from producers. However, changing policies and a lack of standards make it difficult to implement any digital system for documentation verification. Digitization could help with standardization of product quality assurance, but current policies and systems are not set up for it.

This begs the question: *What data governance structures best address both supplier and buyer side concerns?* This question elaborates on how governance issues as mentioned can be overcome.

Both regulatory and voluntary information management regarding fresh produce shipments entering the EU ae in scope of this study. Figure 4 summarizes these information management aspects.

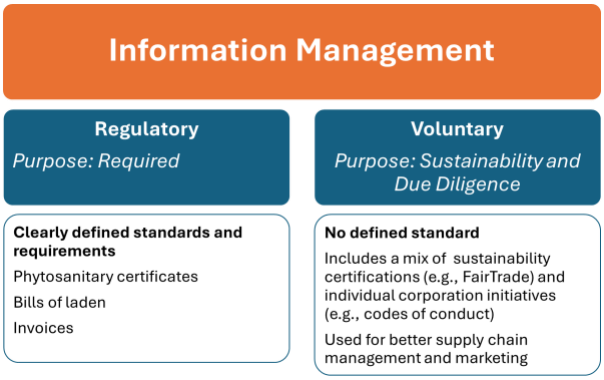

Figure 4: Information management considerations

While our goal is to go beyond requirements, currently, digital systems are not set up for effective and coordinated management of basic voluntary documents. This does not mean there is no path towards exploring digital systems for voluntary information. It simply requires a more holistic understanding of the different functionalities associated with regulatory and voluntary certificates, though these may not be mutually exclusive. Future research can look at both simultaneously, improving digital systems for regulatory certificates can be paired with voluntary information and vice versa.

The following set of questions concern the certification processes associated with both regulatory and voluntary reporting.

How are certification processes informed by specific supply chain contexts? This question highlights the need to perform supply chain mapping to inform the design of visibility systems and explain that specific complexities inform specific requirements and challenges.

How are stakeholders involved in regulated certification processes and what are their needs, what are issues? This question delves into the fact that not all stakeholders have the same needs and requirements, and may trigger governance issues, for example.

How best integrate G2G digital certification with international supply chains? This question addresses UK stakeholder requirements, among which are requirements of supply chain actors, and the supply chain as a whole.

3.2 Approach

Mapping current digital tools and anticipated digital solution by integrating AI, blockchain based technologies is essential to understand and validates changes in the supply chain structure. It involves the identification of scope of potential activities within supply chain and assesses its impact terms of efficiency of integration, decision-making and scalability. The avocado value chain map (Figure 3) details physical and stakeholder structure but highlights the potential implication of digital solutions. By aligning digital capabilities with specific supply chain activities, it becomes possible to pinpoint areas for improvement and ensure that any structural or procedural changes are supported by the appropriate technological tools. Inclusion of stakeholders in this process ensures that the selected digital solutions are practical, relevant, and aligned with operational realities. It also forms a basis for system redesign; where stakeholders are included in this process. Inclusion is an important part of process changes and informed our research questions.

Exploring a particular supply chain allows for identifying potentials for lowering costs and profit benefits in a more tangible way. As the purpose of this paper is to provide a high-level overview, lessons from both cases can be adapted to other supply chains. Any future research should start with mapping the supply chain of interest with detailed analysis of stakeholders, the product requirements, and processes in place that could be enhanced with a digital solution. The technologies we explore do not offer blanket solutions; the merits and capabilities must be assessed to determine which are most appropriate for specific supply chain pain points.

The avocado value chain map (

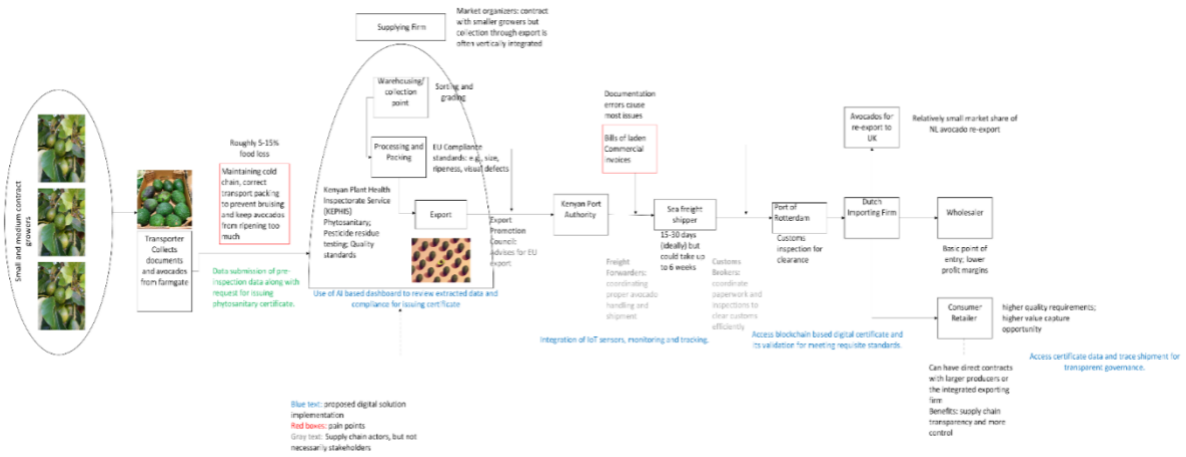

Figure 1 in Part 2) illustrates a first step towards doing this, from which emerged more specific themes of enquiry and Figure 3 proposes digital intervention points. Together, these form a basis for system redesign, where stakeholders are included in this process. Inclusion is an important part of process changes and informed our research questions.

With all these potential research pathways presented, considerations of access and benefits will be important. This includes defining the owners of shared information, what data is being shared and how it is used. Rather than focusing on new investments, it is envisioned to focus on digitalisation of current practices which can be adapted or scaled to enhance the traceability, trust and efficiency in global supply chain operations. Farmers and exporters have a high willingness to adopt digitization given a clear value proposition. It demonstrates the potential of compliance, recording of supply chain transactions providing better access to European markets and were able to gain insights for their own supply practices. It emphasises on usage of digital technologies to enhance coordination and deliver practical value to all supply chain actors equitably.

Because these questions involve diving deeply into the 'how' and 'why' of supply chain relationships, including both product flows and information processing, an exploratory case study would be appropriate. Specifically, embedded single case study design (Kähkönen, 2014). Using this method, the case would be defined as the supply chain in question (e.g., Kenyan avocados) where the unit of analysis would be the relationships between each supply chain partner (e.g., farmer-transporter, farmer-exporter, exporter-wholesaler).

Theory should also inform the application of methods. In this case, we focus on stakeholders as both necessary for digital implementation to achieve ASC visibility and key sources of information that should drive digital design choices. Stakeholders are therefore a vital resource to this project, including low-power ones not traditionally leveraged in SCM research. Sodhi (2015) reconceptualizes RBV beyond the focal firm, developing stakeholder resource-based view (SRBV) as an alternative to integrating social sustainability into supply chain operations. SRBV can be used to study perspective of multiple stakeholder perspectives, not just the focal buying firm (Sodhi, 2015).

3.3 Exploring Digital Solutions

This section will provide next steps for creating a test environment to experiment with, develop and disseminate knowledge about digitalization of certification processes. The FPSC between the Kenya and UK and Netherlands plays a vital role in mapping supply-demand patterns. It involves high volume of fresh produce commodities which is facing numerous challenges due to usage of paper-based phytosanitary certification process. This results in inefficiencies and delays in getting clearance for existing import/export procedures.

Digitalization of the phytosanitary food certificates involves the system integration comprising of the blend of blockchain, AI and IoT based technologies. It refers to the independent role of every technology which drives the common outcome resulting in digitalization of

aforementioned certificates. It can be understood from Figure 3 below which details system layer and functional design of proposed architecture of digital phytosanitary certificates for the proposed tradelines.

IoT based data monitoring

It is entry to the point to information pertinent to the issuance of digital phytosanitary food certificates. It is intended to capture real-time environmental data and shipment traceability to meet the phytosanitary standards. This technology comprises components having sensors integration to capture real-time data inputs, data logging devices to transmit data to cloud, and gateway integration for sharing aggregated data with certificate management system in real-time.

AI-based intelligence

This layer is purposed to process and validate phytosanitary certificates from diversified formats/sources as per the requirement of import/export partners. It comprises of component which accepts certificates in various file formats (online/offline), which extracts key fields and maps it with the requisite standardized data format issued by WCO. Furthermore, it also checks for compliance with the regulatory rules for fulfilment of requirements to issue a digital phytosanitary certificate.

Blockchain-enabled trust framework

It is required for sharing and providing verifiable mechanisms for phytosanitary certificate records. This technology enables inter-country verification of digital version of certificates and records outcomes based upon IoT and AI integration. It comprises distributed ledger to store information, which can also enable smart contracting mechanisms to improve autonomy of verification and validation. Smart contracting is an effective tool for both relationship management and enforcement.

In reference to problems due to the use of paper-based phytosanitary food certificates for the aforementioned tradelines, it can be curbed by its integration with digital technologies. Specifically, in the context of digitalization of phytosanitary food certificates, two critical features focusing on visibility enhancement and capacity building technologies can be considered.

Based upon the training of AI model on a dataset of phytosanitary certificates from Kenya, Netherlands and UK, developed digital system can be able to:

- Identify and extract critical fields (inspection details, issuing authority, data inputs, country specific terminology, and phrasing).

- Normalize different data structure in compliance with world custom organization (WCO) data model and compatible with language translation (Like, Dutch, Swahili and English) required.
- It can also flag discrepancies or missing data fields in issuing digital phytosanitary certificates.

By modernising phytosanitary certification in key trade corridors such as UK–Netherlands and Kenya–Netherlands, we can move beyond fragmented compliance processes toward a fully traceable, resilient, and due diligent food trade system.

4 Conclusion

Chapter 1 sets the stage by presenting a vision toward visibility of fresh produce global supply chains: from compliance to due diligence. With an understanding of the current context of supply chain visibility and the role specific digital tools can play in supporting both regulatory and voluntary supply chain management reporting, the need for change can be clarified. The current situation is addressed while considering various stakeholders.

Chapter 2 develops two use case examples that can be used to illustrate how effective digital implementation can create value for identified stakeholders. Chapter 3 proposes future research to support further development and implementation of digital solutions for a specific fresh produce supply chain. This includes providing questions and a use case methodology that can be applied to future use cases as part of this project. Additionally, specific digital solutions that could solve issues identified in Chapter 1 and 2 are discussed in more detail.

In sum, this work demonstrates how digital technologies can be leveraged to make FPSC operations more visible and integrated. It is not intended to only replace paper-based certificate with digital tools but redefining the supply chain operations logic from reaction to anticipation, from fragmented records to unified data streams and periodic oversight to continuous due diligence. This creates a future-ready, trust-enhanced ecosystem for value fresh produce trade.

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RESULD

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