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STREAMING
Driving EU-African Trade by Food Chain Innovations

Sustainable Trade Regimes with Europe and Africa through Mapping Innovation, New-technology and Growth-mindset – STREAMING

D3.1: AFRICAN DIGITAL LANDSCAPE

DIGITAL SOLUTIONS AND STANDARDS ADOPTED IN THE AFRICAN UNION



Lead Partner: WU

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Summarizing Table

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Abstract:	Digital agricultural transformation represents a shift in the governance, social organisation and institutional structure of agrifood systems, and is a key enabler for improved trade, productivity and market access. Yet, structural challenges and limited understanding hinder sustainable uptake among the African Union. This report analyses and synthesizes the current state of knowledge, capabilities, and digital solutions adopted in Africa, in line with the ambitions of the AfCFTA to establish a continent-wide free trade zone and the priorities of the AU-EU partnership. A successful digital transformation pathway must be inclusive, context-sensitive and aligned with African realities. It requires strong foundational infrastructure, adaptive standards, embedded training ecosystems, coherent governance structures and a commitment to protecting the most vulnerable market actors, including women and children. When co-designed accordingly, digitalisation can advance the aspirations of Agenda 2063, AfCFTA and CAADP, strengthen regional integration and enhance the livelihoods and resilience of millions across the continent.

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Abbreviations

Abbreviation	Meaning
AA	Association Agreement
AfCFTA	African Continental Free Trade Area
API	Application Programming Interface
ATVET	Agriculture Technical and Vocational Education and Training
AU	African Union
AVC	Agricultural Value Chain
ATO	African Trade Observatory
CAADP	Comprehensive Africa Agriculture Development Programme
CCP	Critical Control Point
COMESA	Common Market for Eastern and Southern Africa
CTA	Technical Centre for Agricultural and Rural Cooperation (ACP-EU)
D4Ag	Digitalisation for Agriculture
DAT	Disruptive Agricultural Technologies
DE4A	Digital Economy for Africa
DTP	Digital Trade Platform
EAC	East African Community
EANCOM	Electronic Article Number Communication
EBA	Everything But Arms (EU Trade Initiative Least Developed Countries)
EPA	Economic Partnership Agreement
EPCIS	Electronic Product Code Information Services
EUDR	European Union Deforestation Regulation
ESCAP-ECA-ECLAC	United Nations Regional Commissions: Economic and Social Commission for Asia and the Pacific (ESCAP), Economic Commission

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	for Africa (ECA), Economic Commission for Latin America and the Caribbean (ECLAC
ERP	Enterprise Resource Planning
FBO	Farmer-Based Organisations
GAP	Good Agricultural Practices
GDP	Gross Domestic Product
GM(O)	Genetically Modified (Organism)
GSP	Generalized System of Preferences
GSMA	GSM Association
GTIN	Global Trade Item Number
HACCP	Hazard Analysis and Critical Control Point
IoT / IoE	Internet of Things / Internet of Everything
IPL	Intellectual Property Law
IS	Information Systems
JSON	JavaScript Object Notation
LDC	Least Developed Country
MRL	Maximum Residue Limit
NAND	Not AND - Non-Volatile Storage Technology
PAPPS	Pan-Africa Payment and Settlement Systems
QCP	Quality Control Point
RAM	Random Access Memory
REST	Representational State Transfer
RFID	Radio-Frequency Identification
RTA	Regional Trade Agreement
SADC	Southern African Development Community

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SC	Supply Chain
SCOR	Supply Chain Operations Reference (model)
SME	Small and Medium-sized Enterprise
SOAP	Simple Object Access Protocol
SPS	Sanitary and Phytosanitary
TARGET2	Trans-European Automated Real-time Gross Settlement Express Transfer System
TDI	United Nations Trade Digitalisation Index
UAV	Unmanned Aerial Vehicle
URI	Uniform Resource Identifier
USSD	Unstructured Supplementary Service Data
UTZ	UTZ Certified
XML	eXtensible Markup Language

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Executive Summary

Overview and objective

This report offers a broad overview of the current state of digitalisation relevant to trade in the African agricultural and food (agri-food) products. This is the first deliverable of work package 3 (WP3) of the STREAMING project (*Sustainable Trade Regimes with Europe and Africa through Mapping Innovation, New-technology and Growth-mindset*) and represents the output of Task 3.1, which maps existing guidelines, good practices and digital solutions across Africa that support intra-African and Africa-EU trade. The objective of this task was to analyse the current state of knowledge, capabilities, and digital solutions adopted in Africa, in line with the ambitions of the AfCFTA to establish a continent-wide free trade zone and the priorities of the AU-EU partnership. Through desktop research, extensive bi-weekly discussions with experts within the project and from partner projects, surveys, and field visits and in-depth case studies in Rwanda, it set out to achieve the following objectives:

- assess the current state of digital solutions used for trade in Africa and with European trading partners, and provide an overview of the tools and digital solutions currently in use;
- analyse the current state of knowledge, capabilities, and digital solutions adopted in Africa;
- investigate foundational digital standards and solutions, with a focus on traceability, transparency, and sustainability;
- identify gaps between the current state and the desired future adoption of appropriate digital solutions for shared innovation platforms, electronic trade, market information, quality assurance, transparency, auditing, and certification.

Results

This report covers the results of Task 3.1 as follows:

- First, it outlines the current state of African food system and trade dynamics, the relevant trade agreements, and the major digital transformations supporting these, drawing on the most recent online information from key actors such as the AU, the EU, and the AfDB. Covering all African countries, the report highlights regional differences in current agricultural production, digital solutions and practices, and trade facilitating performance.
- Second, it presents the digital solutions and tools identified in the scientific literature and those used in practice, based on non-academic literature and case study research, in order to understand the gap between the current state of practice and the current state of knowledge.
- Third, it reviews the evolution of digital standards relevant to achieving the African Union's ambitions and the objectives of the AfCFTA in trade with the EU, setting the scene for identifying existing gaps and challenges in achieving the ambitions of both the AU and the EU.
- Finally, it presents key gaps and challenges in the digitalisation of agrifood value chains across Africa and lays the groundwork for subsequent project activities aimed at overcoming trade barriers and advancing digital solutions for trade in African agri-food products.

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This report aim to inform African farmers, digital solution innovators, policymakers, trade organisations, research institutions, and other interested parties in both Africa and Europe through a comprehensive analyses of the current state of knowledge, capabilities, and digital solutions adopted in Africa, while providing a comparative overview of relevant digital standards for trade facilitation that these actors need to consider, as well as the gaps and challenges they need to address.

The analysis draws conclusions based on a wide range of reputable sources including documents and databases from AU, EU, Food and Agriculture Organizations of the United Nations (FAO), World Bank, United Nations (UN), Digital Agri Hub and academic literature. Specifically, it integrates agricultural trade & food-related databases from FAOSTAT & the World Bank, Regional Digital Trade Integration Index (RDTII 2.0), UN Global Survey on Digital and Sustainable Trade Facilitation (UN-TFS) and incorporates a Systematic Literature Review alongside case studies on tea, cassava, and the adoption of Global Standards (GS1) in Rwanda. A multi-layered approach was taken to evaluate not only the current state of trade digitalisation but also policy and regulatory frameworks, regulatory institutional readiness and cross-border paperless trade. By integrating regional and continental policy frameworks, existing Digitalisation for Agriculture (D4Ag) solutions, and field-based case studies, the report aims to offer a holistic overview of the digital landscape of the African agricultural sector, that will inform STREAMING work packages and support evidence-based recommendations aiding to accelerate the African agricultural transformation.

Limitations

While this report aims to provide a comprehensive overview of the African digital landscape for trade facilitation in the African agri-food system, the following major limitations should be noted:

- The African continent has a broad range of nations and regions and thus differ significantly in agricultural agri-food systems, digital readiness, and institutional context. Therefore, a single continental overview cannot fully capture local realities or fully capture local agricultural, technical and cultural contexts.
- Due to the limited availability of peer-reviewed scientific literature, the report relies heavily on documents and online publications from sources such as the African Union (AU) and the European Union (EU). While the sources are reputable and captures the latest developments, the unverifiable nature of some documents limits the scientific rigor of the findings.
- Publications on digital trade facilitation in Africa are limited and concentrated in a few countries. Although the survey covers multiple countries, the in-depth case study focuses only on Rwanda, restricting the geographic representativeness of the findings.
- The in-depth analysis focuses on two specific agri-food products. While this allows for detailed insights, the findings may not be fully generalisable to all agri-food sectors.
- This report presents a snapshot of the African Digital Landscape and does not capture potential future developments and/or innovations.

This report is part of a series of deliverables of WP3 and, as one of the first outputs of the project, provides valuable inputs for subsequent tasks and forms a sound foundation for other deliverables (D3.2 to D3.4) to come. It is also worth noting that some of the limitations in this deliverable, such as the restricted geographic and agri-food sector coverage, will be addressed in follow-up project deliverables.

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1. Introduction

1.1. Motivation and objectives

The African continent holds a crucial position in global food systems, with over 60% of arable land and a rapidly growing population, agri-food systems play an essential role in ensuring food security, employment, and economic growth. In most AU member states, agriculture remains the primary source of income, employing more than half of the population. However, despite its dependence on agriculture, Africa not only lags behind other regions in terms of productivity and has become dependent on food imports, but it also faces complex trade regulations, non-tariff barriers, and high tariffs both within the continent and in trade with the EU and other international markets. Cumbersome customs procedures, stringent sanitary and phytosanitary standards, and inconsistent policies are further exacerbated by the lack of digitalisation, creating additional barriers to trade and growth in the agricultural sector.

The adoption of digital technologies in the agricultural sector offers a significant potential to advance the sector, enhancing efficiency, sustainability and the continent's competitiveness in international markets. Digitalisation of food systems can enhance market access, traceability and transparency, benefiting both food safety, security and open economic opportunities. In doing so, digital technologies can also help mitigate the effects of non-tariff barriers related to documentation, traceability, and other cumbersome customs requirements. Africa is a large continent, comprising 54 countries that vary widely in their levels of involvement in agricultural trade and in their adoption of digital technologies. The digital landscape across Africa is highly fragmented, characterised by uneven performance between regions. Unfortunately to date, there is a lack of a comprehensive, systematic overview on the digitalisation of agricultural trade and related goods originating from Africa.

This report aims to address this crucial gap in knowledge and maps existing guidelines, good practices, standards and digital solutions that support intra-African and Africa-EU trade, in-line with the ambitions of the AfCFTA to create a continent-wide free trade zone and the goals of Africa-EU partnerships, which aim to improve market access for African agricultural goods. It provides a comparative overview of digital solutions, regulatory factors, trade facilitation initiatives and innovative solutions, with the aim to inform African farmers and innovators, policy makers, trade organisations, and research institutions in both Africa and Europe about the current digital landscape for trade in Africa and the actions needed to enhance it.

1.1.1. Methodology

To map the African digital landscape for trade within Africa and with Europe, a multi-layered approach was taken to ensure triangulation and deeper comprehensive insights into the African digital agricultural landscape. Biweekly meetings with consortium partners (WU, BITMi, GS1, ICT Chamber Rwanda) ensured fruitful discussions to ensure integration of multiple perspectives. The methodology combined quantitative and qualitative analysis, integrating academic and institutional information sources, outcome of case studies, and survey results:

- **Desk research:** Analysis of academic and grey (governmental/institutional) literature to provide context on the current digital landscape in African agricultural value chains.
- **Systematic Literature Review**: Structured review of four academic databases (Scopus, Web of Science, ScienceDirect and IEEE Xplore) to identify academic trends,

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insights and innovations in digital agriculture and trade on the African continent.

- **Trade and Digitalisation datasets**: Analysis of datasets, including FAOSTAT, World Bank, Regional Digital Trade Integration Index (RDTII 2.0), and UN Global Survey and Sustainable Trade Facilitation (UN-TFS) to quantify trade facilitation performance, current state of digital standards adoptions and trade trends & insights.
- **Case studies**: In-depth reviews of selected agricultural value chains, including the African tea & Cassava value chain as well as practical findings from the implementation of GS1 Rwanda. The case studies were based on desk research, conducting surveys and field research.
- **Policy & Regulatory Framework analysis**: Review of continental and regional (trade) frameworks, agreements and commitments, including the AfCFTA (Digital Trade Protocol), CAADP and Agenda 2063 to align with the ambitions of the continent on governmental structures and readiness on cross-border paperless trade.
- **Survey study**: An online survey was conducted to key stakeholders and STREAMING partners to capture practical insights on digital solutions in the agricultural sector. Future surveys, presented in upcoming deliverables, will focus on capturing insights into local and international trade, (smallholder) farmers, traders and intermediaries, as well as the socio-cultural context (see Annex VII – Initial STREAMING Survey (2025)).

1.1.2. Main Research Question

The main research question this report addresses is:

Which existing guidelines, good practices and digital solutions currently support intra-African and Africa-EU trade, and how do they align with the standards, capabilities and solutions necessary for a scalable and sustainable digital trade ecosystem?

The question is addressed through answers to the following targeted sub-research questions:

1. What is the current state of Africa's food systems, agricultural trade, and agreements?
2. Which regulatory frameworks currently support digital agricultural trade, and how do they support cross-border paperless trade?
3. How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?
4. What types of digital agricultural solutions are currently being used across Africa and what do case studies reveal about success, challenges and opportunities of digital tools?
5. What are the gaps between the current state of digital solutions and the ideal future state required under AfCFTA and Africa-EU trade aspirations?
6. Which opportunities are arising from agricultural transformation to strengthen and accelerate agricultural production, quality assurances, transparency and market access?
7. What actions, policies and continental strategies are needed to accelerate trade digitalisation and digital innovation to enhance cross-border interoperability and support smallholder farmers and SMEs?

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1.1.3. Scope and Purpose

Despite rapid technological and economic advancements in the African continent, detailed reports of an African-wide overview of existing digital practices and standards within the agricultural value chain are scarce. Current literature provides a general overview of digital infrastructure across the continent, albeit focused on a limited set of countries or specific examples of digitalisation, such as the *Digitalisation African Agriculture Report* by CTA (2018) and the recently released *Digital agriculture in FAO projects in SSA* by FAO (2024) [1], [2], but a comprehensive overview of digitalisation in support of trade is still lacking. This report develops an integrated overview of the often fragmented academic and non-academic sources into one single report. This report integrates theoretical perspectives with practical solutions and illustrates this with select case studies. It aligns its findings with global standards, trade instruments and regulatory governance.

Being part of the STREAMING project, which aims to support the development of fair and sustainable trade regimes between Europe and Africa, this reports targets to address the goal of the project in terms of mapping innovations and technologies thereby bridging the gap between current practices and knowledge and the desired outcome of achieving healthy and environmentally sustainable food systems across the African continent. The scope in this regard is supporting the facilitation of trade among African countries and with Europe and thereby promoting a growth mindset.

The scope is also limited to offering empirical evidence to inform African farmers and innovators, research institutions, policy makers in Africa and Europe, trade organisations, health organisations, and other interested parties about the current state of the digital landscape for trade and the actions required to enhance it. This report is the result of intensive collaboration among the members of WP3—Wageningen University, Bundesverband IT-Mittelstand e.V. (BITMi), GS1 Germany GmbH (GS1G) and Rwanda ICT Chamber (ICTC) — and lays the foundation for follow-up deliverables, including a policy-recommendation report, digital learning materials for digital trade, and the creation of innovation e-Learning platform.

The overarching goal of WP3 is to support the development of digital ecosystems that support the adoption of trade standards, guidelines, and best practices—particularly those related to digital product tracking and tracing to enhance transparency—and to promote the interoperability of the African trade and food safety systems within globally adopted digital trade frameworks. To achieve this, it is necessary to develop an understanding of the African and Africa–Europe agri-food supply chains, and the associated governance mechanisms within the STREAMING project, and this report contributes to that objective.

To provide concrete examples of the issues associated with trade and digitalisation, this report also includes the results of two case studies with the focus on the African cassava and tea product value chains. In this report we focus on the targets of AU's CAADP, AfCFTA, and Agenda 2063 as key governance structures underpinning AU-EU trade. A more in-depth analysis of addressing non-tariff measures across diverse African countries and product value chains—including aspects related to transparency—will be carried out in the relevant STREAMING work packages. In addition, a concise, reader-friendly version will be created and disseminated to summarise the main findings.

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1.1.4. Links to other EU projects

Figure 1: Logos EU-funded sister projects [3], [4], [5]

The report draws on a number of related sister projects, particularly the EU-funded Food Safety for Africa (FS4Africa) and Food Convergence Initiative for Africa (FCI4Africa), with which the STREAMING project has a memorandum of understanding. It also builds on past EU-funded initiatives, such as the CTA (Technical Centre for Agricultural and Rural Cooperation), where substantial work on digitalisation relevant for the goals of this project has been or is being carried out (see Figure 1).

FS4Africa: The FS4Africa project aims to improve food safety systems in Africa, particularly the informal sector, by strengthening food safety at the source with technology and innovation in local agricultural value chains (see Figure 2). The project aims to support trade by strengthening food safety governance, traceability, and regulatory compliance across African agri-food value chains. It aims to lower costs for certification and conformity assessment, and to reduce non-tariff barriers that limit market access for informal and small and medium-sized enterprises. By addressing key hazards such as aflatoxins and pesticide residues, the project reduces rejections, increases market opportunities, and enhances trade readiness under the AfCFTA framework. WP3 of the STREAMING project builds upon these food safety improvements by enabling digital traceability. It aims to achieve this goal through the adoption of digital interoperable standards, thereby enabling African countries to conform to international trade and traceability standards and guidelines, and scaling up intra-African and Africa–EU trade.

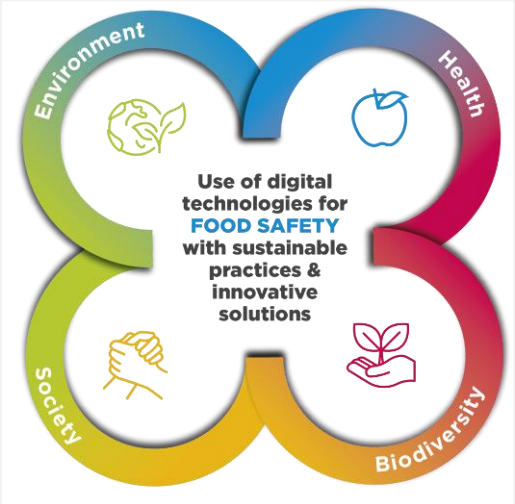


Figure 2: Vision Food Safety for Africa [4]

FCI4Africa: FCI4Africa, a sister project of STREAMING, pursues objectives similar to STREAMING but employs the Food Convergence Innovation (FCI) approach to address inequitable trade practices while enhancing the climate-neutrality of African products. Through

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this holistic FCI approach, the project integrates technical compliance for traceability and conformance to sanitary standards, while considering the associated social factors across multiple levels of societal hierarchies. The project aims to integrate knowledge, behavioural change, organisational transformation, and investment and policy frameworks to support scalable, evidence-based solutions for climate, economic, environmental, and social outcomes across multiple levels, from local communities to international markets. As in STREAMING, it builds on the FS4Africa project but complements it through its holistic FCI approach and the selection of a different set of use cases conducted in a different set of countries.

Related past EU initiatives: The STREAMING project builds on lessons learned from previous EU-funded initiatives, including the several digital innovation initiatives carried out by the Technical Centre for Agricultural and Rural Cooperation of ACP-EU partnership (CTA) and the outcomes of several projects funded under the AU-EU FNSSA and DeSIRA programmes. These initiatives not only contributed to the digitalisation of African agriculture but also supported the formulation of the AU's Digital Transformation Strategy and its recent Kampala CAADP Declaration. The WP3 of the STREAMING project aims to contribute to the realisation of the ambitions set out in the CAADP Declaration

1.1.5. Links to other deliverables

This report is the first of the four deliverables of WP3, and as such, it lays the groundwork for the remaining three deliverables (D3.2, D3.3, and D3.4). It also contributes to the deliverables of other WPs. The most important linkages are outlined below:

- **D3.2**: This deliverable provides policy recommendations addressing the gaps for adopting and scaling up digital solutions and standards in Africa. This deliverable directly builds on the findings of D3.1 (this report).
- **D3.3**: This deliverable provides a digital innovation platform, which is a virtual collaboration platform to support networking of farmers, start-ups, and other stakeholders, and to facilitate the implementation and use of digital solutions and standards in Africa.
- **D3.4**: This deliverable provides training materials and the actual training to diverse stakeholders on capturing and sharing data for traceability.
- **D5.3**: This deliverable manages the second open call focussed on knowledge grants for building online courses. The grant specifications will be informed by the outcomes of this deliverable and its subsequent deliverable, D3.2.

Besides the direct linkages with the above deliverables, this report will serve as a useful foundational reference for other deliverables of the project.

1.2. Key Concepts: Information Systems & Digital Agricultural Trade

The report is focused around two key concepts, building upon the importance of socio-technical information systems and understanding the role of digital agricultural trade systems that support the African Union's digitalisation commitments.

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1.2.1. Information Systems

Information Systems (IS) exist to support people in organizations with their decision making and are a fundamental aspect to understand how modern firms operate.

"An information system is a set of interrelated components that collect (or retrieve), process, store, and distribute information to support decision making, coordination, control, analysis, and visualization in an organization."

Source: Management Information Systems: Managing the Digital Firm by Laudon et al. (2022) [6]

An IS can be divided into a formal and informal system. A Formal Information system is manifested by documents and other records and has a well-defined procedure. An Informal System is accessible by any user in the organization and follows procedures and actions that are not formally described in operational procedures.

Information Systems are the backbone of any modern organisations and consists of two main systems: Social Systems and Technical Systems (see Figure 3)

- Social systems are comprised of structures (organisational roles) and people (users, managers).
- Technical systems consist of technology (**information technology**; hardware devices, software tools and telecommunication devices) and processes (workflows, rules).

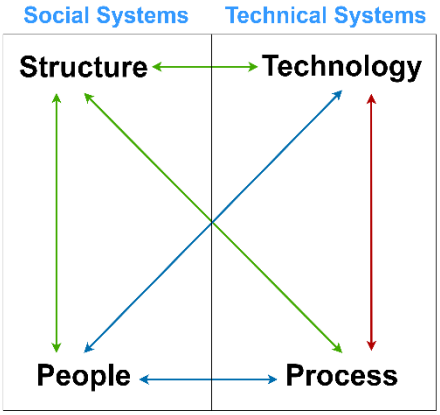


Figure 3: The components of an Information System

Digitalisation transformation can be understood through three changes. **First Order Change: Automate** involves change between technology and processes, replacing or automating existing tasks or processes using technological solutions. These changes are often incremental and do not alter the fundamentals of the system. **Second Order Change: Informate** involves change between people, technology and processes, and fundamentally brings changes between the social – and technical systems. Instead of incremental automation, second order change involves revolutionary change, shifting the "*what*" to "*how*" we understand, interpret and use information. Many of the digital solutions for agriculture in Africa, such as mobile money, market information and digital extension services fall under this category. These solutions allow smallholder farmers and SME to improve their decision making, efficiency and transparency, fundamentally changing agricultural practices. **Third Order Change: Transform** is a substantial change between structure and technology (use and manage technology), structure and people (changes in authority structures), and structure and processes (redesigning of workflows). It involves a fundamentally shift in underlying assumptions, identity, purpose and core models, creating entirely new ways of functioning. The agri-food transformation approach & commitments from the AU indicate moving beyond incremental improvements and build towards long-term transformation, with digitalisation as a key drivers.

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Cultural context influencing digitalisation

> *"The collective programming of the mind that distinguishes the members of one group or category of people from others"*
>
> **Source: Dimensionalizing Cultures: The Hofstede Model in Context.** [7]

Beyond technical – and social transformation, the role of culture in organizations and countries also play a crucial role in understanding system transformation and organisational behaviour. National and organisational cultures influence trust in authorities, long-term (investment) orientation and uncertainty tolerance, all of which influence the uptake and adoption of new (digital) solutions in current (agri-food) practices (see Annex VI – Hofstede's Cultural Dimensions for a detailed explanation of the six dimensions affecting organizational culture). It affects how the introduction of digital systems should be governed and adjusted to fit a specific cultural context. In the African agricultural context, informal systems for agriculture trade - markets, social norms/institutions, unwritten rules – operate on the consensus of collective norms & behaviour that is expected in a specific context and plays a major role in current day-to-day agricultural trade practices. This report therefore aims to explicitly address both formal – and informal systems, understanding that improving digitalisation and trade under African Union commitments (AfCFTA, CAADP) requires interlinking both systems, fitting the local cultural context.

Understanding the dynamics between these four components is essential to understand how digitalisation works, together with the cultural context they operate in. Digitalisation is not purely a technical dimension, it is a socio-technical system that requires the integration of human behaviour, organisational processes and the adoption of technology that work intertwined. Agricultural transformation is not solely dependent on technology alone, instead it only works effectively when all components utilise each other in harmony. Understanding these four components of information systems and its role in socio-technical systems, we can better understand the opportunities and challenges of implementing digital solutions in African agricultural value chains, and why coordinated actions across people, structures, process and technology are essential to build towards a sustainable agricultural trade ecosystem.

1.2.2. Digital Agricultural Trade

Digital technologies can be defined as digital systems, tools, and devices to store, process and transmit data in electronic form across the value chain [9]. **Digitisation** refers to the process of converting analog information into digital format, while **digitalisation** leverages digitization and digital technologies to improve processes and businesses.

> *"… digital products or processes that support the execution of agriculture and related processes for more effective service delivery and access. This can include but is not limited to "digital agricultural technologies" (infrastructural cables, masts, wireless routers, etc.) and hardware (e.g. mobile phones, sensors, blockchain, drones) required to operate, offer and access digital services and solutions."*
>
> **Source: Digital Technologies in Agriculture and Rural Areas Status Report** [8]

In the context of agricultural and food trade, the increasing 'datafication' – transforming real world insights into machine-readable formats – is becoming a central part in food chains. This trend is driven by changing consumer - and regulatory demands who put more value into product attributes such as transparency, product origin and sustainable practices, particularly considering climate change. Combined with advances in hardware, sensors technologies and new emerging technologies such as AI, digital transformation brings change by offering new opportunities to reduce longstanding (regulatory) constraints by digitalisation in agricultural value chains. The increasing capacity in the sector to capture and use data allows monitoring

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and optimisations of quantified digital data that was previously financially or technically infeasible.

This increased datafication in the sector allows data flow to reach beyond the individual actor, but rather throughout the entire chain. These tools now support various agricultural trade-related functions, such as market - & partner discovery (market information systems), improved food safety compliances & agricultural practices (extension services, trade documentation), enhanced transaction efficiency (documentation, payment, logistics). In general, the access to these digital tools – emergence of internet-based platforms and mobile applications - reduces information asymmetry and transaction costs in the AVCs, lowering market participation barriers and creating opportunities for new actors to enter the international market. In particular, new digital platforms and applications are available in remote locations through telecommunications, offering smallholder farmers and SMEs in these regions (increased) access to agricultural knowledge, market access possibilities and other services that previously required physical presence of experts. This is leading to a shift in traditional agricultural practices and trade participation.

Cross-border Paperless trade

"'paperless trade' entails the adoption of electronic formats, replacing traditional paper-based documentation systems, with the aim of expediting trade processes and reducing associated costs".

Source: Trade Digitalisation Index, UN ESCAP [10]

International trade has shifted over the past two decades, with increasing trade relationships between developed and developing economies, and the emergence of global agricultural value chains (GAVCs) [11]. Digital transformation is an important contributing factor, creating new opportunities to support and optimise agricultural processes.

The increasing datafication of the sector brings transformation in trade-related processes that replaces paper-based analogue information methods (e.g., trade permits, certifications, customs declarations) and is an important factor given the global changing requirements, especially the increasing (sustainability) documentation requirements under the EU's Green Deal (deforestation/integrated pest management) for cross-border Africa-EU trade. In addition, paperless trade is also a critical enabler to enhance supply chain resilience, compliance and transparency, especially with the evolving environmental and social sustainability requirements. Despite the known benefits, paperless trade remains at an early stage of digitalisation globally, with the needed trade policies and steps required to reap the full benefits still not well understood [12].

The transformation towards paperless trade involves five key steps [13]:

1. **Digitalisation in trade-related documents**; transformation of paper documentation required for buying, shipping and paying agricultural goods into digital format (following UN/CEFACT Buy-Ship-Pay Model).
2. **Digitalisation in trade-related processes**; automation and use of technologies to streamline trade processes (submission and processing of documentation, pre-arrival payment of duties, fees and charges, Trade Single Window, digital twin accompanying physical goods flow).
3. **Adoption of digital technologies**; use of technologies such as Electronic Data Interchange (EDI) to automate, complete and share trade-related processes. This includes both hardware – and software solutions, such as IoT, blockchain and AI.

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4. **Standardisation of data elements**; streamlining of machine-readable data elements for digital trade facilitation, following for example Global Standards 1 (GS1) or UN/CEFACT standards to streamline documentation such as electronic invoices and Sanitary – and Phytosanitary (SPS) requirements.
5. **Adoption digital regulatory environment**; regulatory - and legal frameworks to enable domestic and international adoption of paperless trade, including supporting policies, data exchange agreements and legal recognition conducting transactions electronically.

Digital technologies operate in a hierarchy of business processes and provide the foundation of specific business – and software processes. These processes are embedded in the business – and regulatory context the firm is operating in. Digital transformation requires more than only technological adoption as highlighted in the socio-technical system transformations, and requires synergy across technology, software, processes and organizational/business context (see Figure 4).

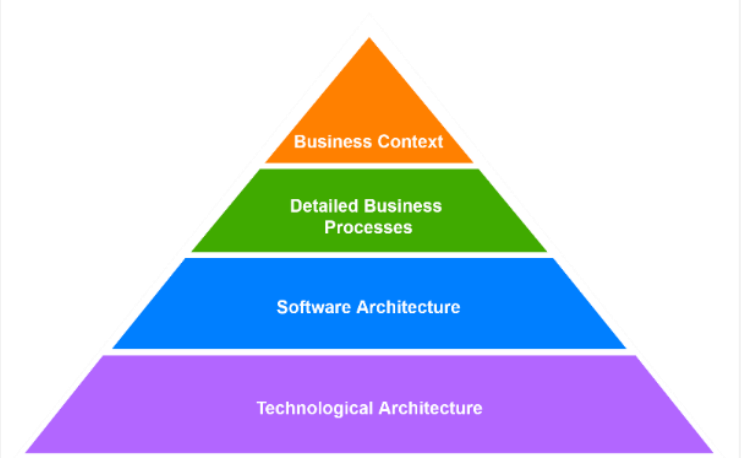


Figure 4: Hierarchy of Roles in Digital Architecture within Socio-Technical Systems

The adoption of digital tools and paperless trade practices are important enablers of agricultural transformation, given the changing global consumer expectations and regulatory trends driven by the need for increasing climate-resilient agricultural practices. Given the benefits of digitally-enhanced agricultural practices and trade-benefits, digital solutions makes previously considered financially – and technically infeasible options now possible, particularly in developing countries, leading the way to fundamentally change how agriculture is performed.

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1.3. Report Outline

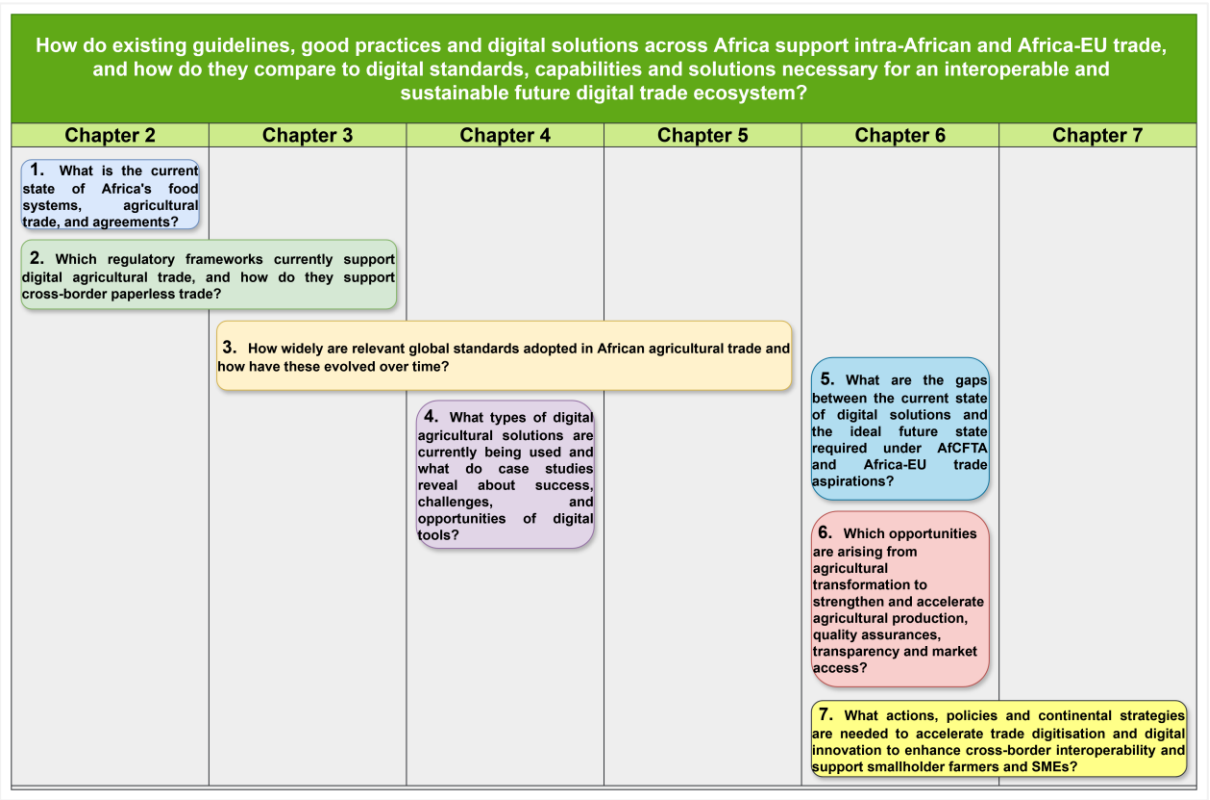


Figure 5: Overview research questions & chapter

The *Digital Solutions and Standards adopted in the African Union* is divided in the following sections: Chapter 2 - Role of Innovative Solutions in Developing Sustainable Food Systems in Africa offers the current state of Africa's food systems related to trade (both formal and informal), commitments and current transformation trends, and draws insights from desk research and Trade & Digitalisation datasets. Chapter 3 - State Digital Infrastructure supporting Agricultural Trade provides an overview of current digital infrastructure developments, a detailed overview of Africa-EU trade requirements, and regulatory trade performance. Chapter 3 draws insights from desk research, Policy & Regulatory frameworks, case studies and Trade & Digitalisation datasets. Chapter 4 - Digital Solutions and Tools in Practice - Findings from Case Studies offers the findings from the Systematic Literature Review, Case Studies into the tea & cassava value chain related to digitalisation and food safety standards, and insights from establishing GS1 Rwanda. Chapter 4 draws insights from systematic literature reviews, desk research, Policy & Regulatory framework analysis, Trade & Digitalisation datasets, case studies and a conducted survey. Chapter 5 - Evolution Digital Standards Landscape present a historical background section on how business standards for trade facilitation, food standards and more came into being, linking the importance of these standards to current and future developments in Africa's agriculture. Chapter 5 draws insights from desk research. Chapter 6 – Addressing the Gaps and unlocking Future Opportunities presents an expanded and refined first-draft analysis of the key gaps, challenges, and preliminary recommendations for digitalisation in agrifood value chains across African partner countries. Chapter 6 draws insights from desk research, a conducted survey and Trade & Digitalisation Datasets. Chapter 7 – Moving Forward synthesises the analytical and empirical findings from chapter 2 – 6, outlining a five-page framework for guiding digital agricultural transformation destined for the agri-food value chain, institutional stakeholders, authorities and IT providers and concludes

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the report on the potential of digitalisation and data-driven standards in the agricultural chain. Figure 5 showcases a general overview of the research questions and the chapter contribution, with a detailed overview per chapter section in Annex I – Overview Sections Sub-Questions and Evidence[1].

[1] (Editor's note) Some portions of the report have been reviewed and checked with AI-based grammar and style support. Language: British English.

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2. Role of Innovative Solutions in Developing Sustainable Food Systems in Africa

Chapter 2 provides an overview of Africa's food systems, trade dynamics and relevant agreements, highlighting key trends, challenges and current practices. An overview of relevant trade agreements and regulatory frameworks supporting (digital) agricultural is next, highlighting regional differences in trade facilitation and both, the role of the formal and the informal sector. Finally, this chapter also addresses the role of innovative, agricultural digital solutions and the existing agricultural trade data between Africa and EU. It draws insights from desk research and Trade & Digitalisation datasets. This chapter helps shape the foundational background needed for the subsequent research questions and addresses research question 1 directly:

1.	What is the current state of Africa's food systems, agricultural trade, and agreements?

Chapter 2 shows that while agricultural is the backbone to Africa's economy and food security, the sector is hindered by low value additions, limited productivity and reliance on food imports. Continental initiatives, such as the AfCFTA, CAADP and national digitalisation strategies offer opportunities to address these constraints by strengthening intra-African trade and improve the sector's resilience to drive socio-technical transformation in Africa's agri-food systems.

2.1. Background on Africa's Food Systems

With over 60% of the world's arable land, agriculture remains a fundamental aspect of economic development in the African Union (AU), playing an essential role in ensuring food security and employing a large part of the population (see Figure 6).

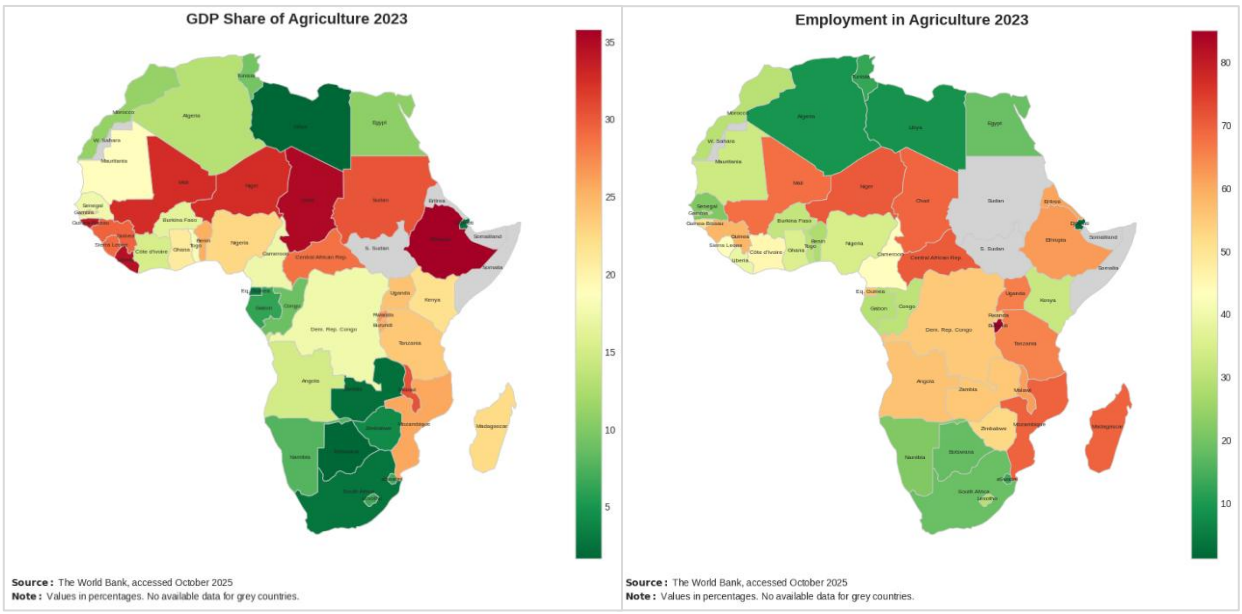


Figure 6: (L) GDP share in agriculture and (R) Agricultural employment share

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Agricultural production is deeply rooted in the culture and livelihoods of millions of Africans and consists mainly of smallholder farmers – farmers working on up to 10 hectares [14] – who produce around 90% of the local food production [1]. In most of the AU member states, the share of agriculture remains the primary source of income, accounting for 56% of its population [3]. However, despite its high dependence on agriculture in most but not all Africa's economies, Africa lags behind other regions in terms of the value capture and the productivity per hectare from its agricultural products, being primarily commodity-driven and thus failing to capture the processing value-added benefits of intermediate products (see Figure 7 and Figure 9) [15]. A

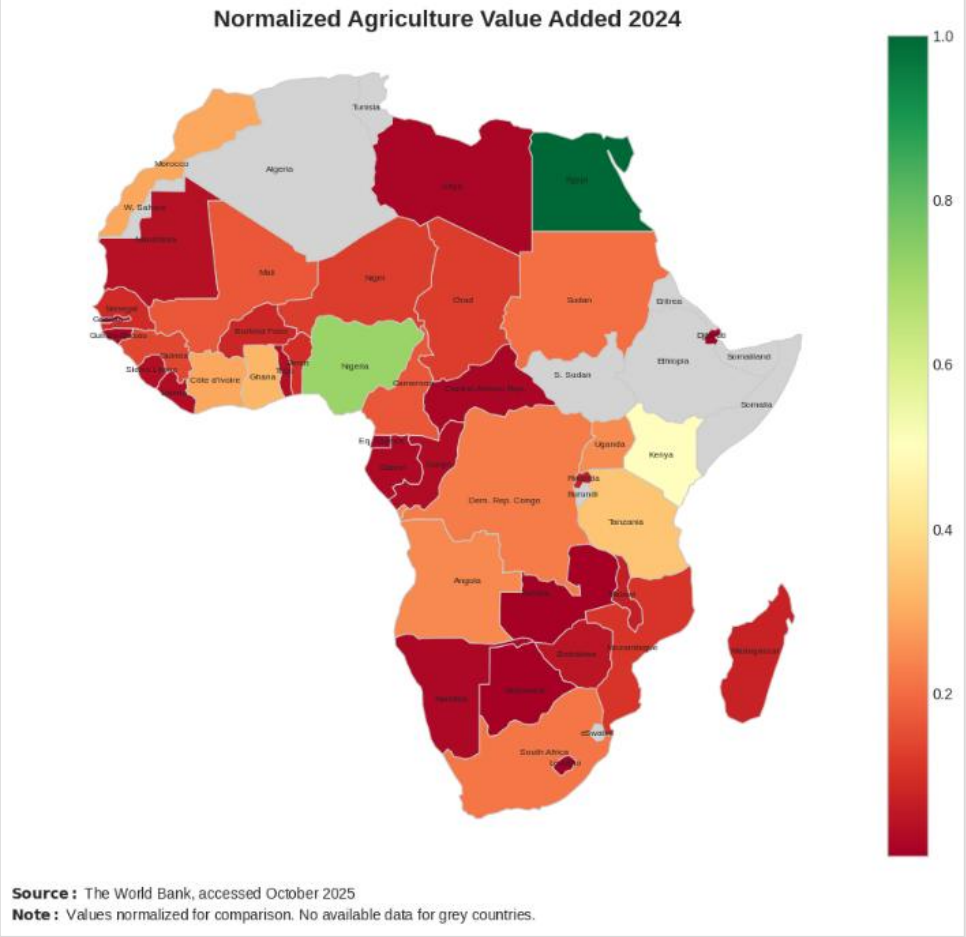


Figure 7: Agricultural value-added commodities in Africa, with Egypt, Nigeria, and Kenya capturing the highest share of value addition.

notable example is the cocoa export sector in West-Africa, exporting over 70% of the world cocoa beans by weight, but only capturing 20% of cocoa's intermediate products [16].

Alongside the limitations in productivity and value capturing, the African food system faces several challenges, primarily stemming from challenging soil conditions and climate change, hindering its ability to effectively contribute to food security and broader economic development. Despite the high dependence on agriculture in their national economies, many AU countries still rely on food imports to meet growing domestic demand, with projections indicating that these food imports will keep increasing in the upcoming years [4]. Projected estimates indicate population growth from 1.5 up to 2.5 billion people by 2050 on the continent, resulting in a further increase of the already high dependence on foreign food imports, which his expected to increase by 2030. Pressure on the food system due to climate change, political instability and other (geo-political) external developments further highlight a need for resilient

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and sustainable food systems to align with future external shocks and developments to feed the population. Currently, Africa has 9 out of the 10 most vulnerable countries to climate [17] . Despite Africa's heavy reliance on food imports, current agricultural trade practices between neighbouring African countries remain low, averaging less than 20% of total export value [18]. The remaining goods, primarily commodity-driven products, are exported outside Africa, leaving potential benefits from value-additions unutilised. As a result, it leaves the continent dependent on commodity export and its price fluctuations. Improvements in intra-African trade offer opportunities to align food production with regional demand, contribute to African job growth, reducing net food imports outside the AU while simultaneously eradicate hunger and food insecurity.

2.2. State of Africa's Agricultural Production and Trade Dynamics

The current developments in the agricultural sector of the AU on the trade agreements – as well as socio-demographic development – urge the continent to redesign the food system and ensures it becomes a sustainable, resilient, and fair market, fulfilling the ambitions of Agenda 2063 and the renewed CAADP, with the AfCFTA playing a key role in achieving these goals. With this transformation, the continent aims to eliminate hunger, reducing poverty, create new jobs, transform its industry with more value-added products and make the continent a world player, shying away from its colonial and neo-colonial past [19]. Despite the strong commitments, several transformations of the African food systems are needed. To start with, 1) eliminating non-trade tariffs between countries and establishing long-term partnerships, and 2) ensuring that neighbouring African countries have uniform access to the AU markets, are essential steps to transform the food system to a harmonised, uniform market.

Intra-African trade of food products plays a major role in these commitments and proposed partnerships, given Africa's primarily agricultural driven economies. With increases in intra-African trade, the continent could become less dependent on food imports from outside the AU by better aligning with regional food production, generating value that stays within the continent between African countries. Currently, intra-African trade has been historically low, hovering around 20% of the continent's total export, with South Africa contributing to almost a third of this intra-African trade [18]. The continent's CAADP commitment of tripling intra-African trade by 2035 requires increasing investments in the continent's infrastructure, both in soft and hard infrastructure, with an emphasis on climate resilience. Creating a harmonised uniform market requires standardisation techniques, aligning with global standards on documentation, track & trace and food quality standards to transform agricultural trade by making it safer, faster and more sustainable [20].

As part of the AfCFTA, the **Pan-African Payment & Settlement System** (PAPSS) is being developed, with already a select group of countries benefitting from seamless cross-border payments [21]. The PAPSS aims to simplify cross-border payments, eliminating intermediaries and dependence on foreign currency. Similar to EU's **TARGET2/T2**[2], simplifying and reducing transaction costs with additional risk-averse measures targets to improve intra-African trade and offer benefits to all stakeholders in the African market infrastructure [22]. Alongside the development of the PAPSS, the AfCFTA offers additional tools to facilitate intra-African trade. Specifically, the **AfCFTA's Non-Tariff Barriers online reporting tool** allows (agricultural)

[2] Financial market structure that facilitates real-time gross settlements.

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stakeholders to report any obstacle and/or submit complaints encountered during trade practices [23].

Inter-African trade stands to benefit from improved standardisation in the sector as well, encouraging cross-border transaction by improving the continents global market integration [19], [24], [25], [26]. Nevertheless, inter-African trade is regionally divided across the continent, with certain economies accounting for most of the continent's agricultural export. As a result, trade imbalances persist, leaving smaller or less developed countries to fall behind. Understanding these imbalances is necessary to fully map the current state of intra- and inter-African trade considering the agricultural developments aiming to transform the continent's agricultural industry.

Despite projections for higher food imports in upcoming years, regional differences in Figure 8 highlights how East and Southern Africa lack behind in terms of foodstuffs destined for human consumption in 2023 compared to the rest of Africa (see Figure 8). By considering the net balance of food imports, it becomes clear how North (which has less agricultural land than SSA) and Western Africa import proportionally more food. Central – and Southern Africa on the other hand import almost as much as the amount of their export values.

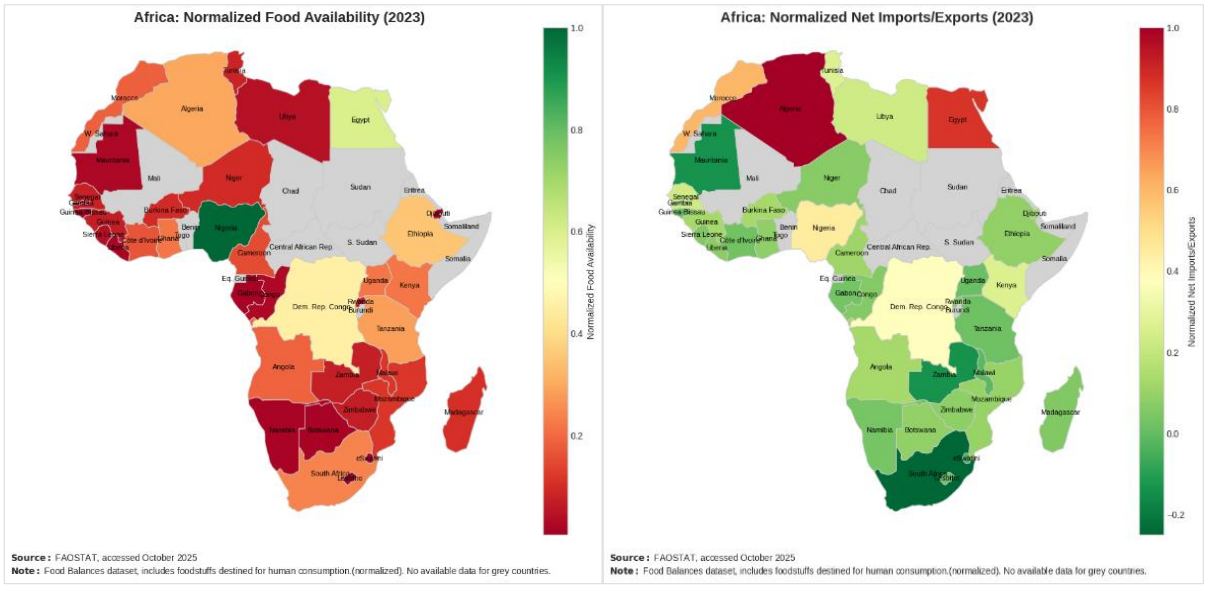


Figure 8: Food Availability & Net Food Imports 2023

It should be noted that big economies, such as South Africa, export almost a third of the continent's intra-African food trade, making the region a large contributor to its near net import value. A noticeable trend is the increase in both importing - and exporting of foodstuffs across all countries on the continent compared since the early 2000s. This falls in line with the increasing population and the effect of agricultural development programs such as CAADP putting further emphasis on food exports, with its ambition of tripling intra-African agricultural trade by 2035.

The intra-African trade of agricultural products remains low, hovering on average around 20% of the continent's total agricultural trade [27]. The importance of boosting this number has been outlined in detail under the renewed CAADP and the AfCFTA. Outside these two agreements and the 8 Regional Economic Communities (RECs) such as COMESA and SADC, the

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importance of becoming less dependent on food imports from outside Africa is a major strive among the African Union.

Among Africa's many small-and medium-sized farmers, accounting for roughly 80% of the AU food industry and producing about 90% of the region's food, access to digital solutions offers opportunities to mitigate current challenges faced by smallholder farmers in the agricultural sector, often resulting from challenges such as information asymmetry, limited access to financial options and cold storage facilities, and climate-related risks [1], [28]. The benefits of higher crop yields and improved access to knowledge through digital tools enable much-needed improvements in Africa's comparatively low yields per hectare of agricultural products, as shown by Figure 9 [15].

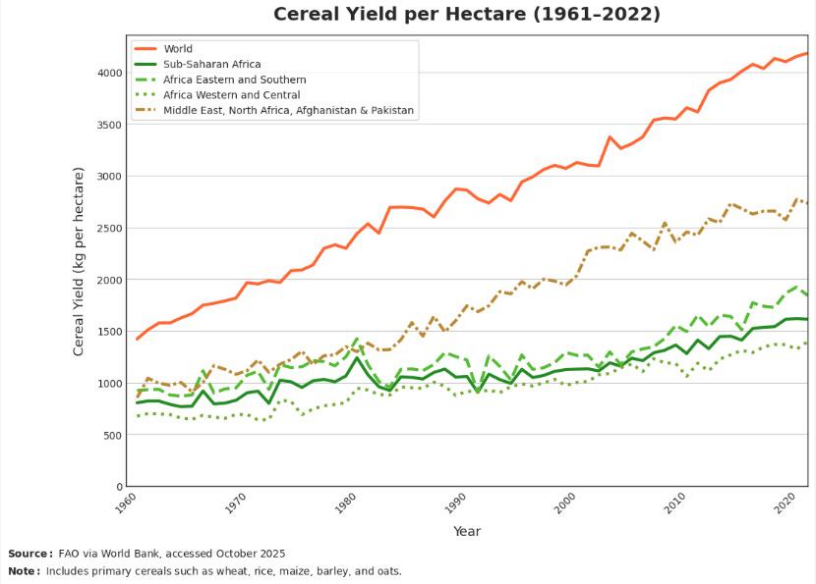


Figure 9: Cereal yield (kg/Ha) 1961 – 2022

While improvements in agricultural productivity are urgently needed, improved trade relations are essential to ensure inclusive and sustainable growth through agricultural improvements. Agenda 2063 and the establishment of the African Continental Free Trade Area (AfCFTA) are the foundational pillars for growth across the continent.

2.3. Trade Agreements & Commitments

A recent shipment of meat, fruits and other agricultural products produced in Ethiopia, destined for Somalia, Kenya and South Africa, outlines a milestone for the AfCFTA trade area and the continent [29]. The 54-country trade initiative aims to eliminate trade barriers, boost intra-African trade, and improve harmonisation in the African market, thereby promoting commodity-based industrialization. Before the introduction of the AfCFTA in 2018, trade commitments and cooperation existed before such as the East African Community (EAC, 1967), Common Market for Eastern and Southern Africa (COMESA, 1994) and the Southern African Development Community (SADC, 1980). While these regional agreements offered benefits to certain members, none came close to a Union-wide approach. The AfCFTA is built on the foundations of these previous trade agreements across the continent.

Trade agreements with external partners, including the EU's Economic Partnerships (EPAs) and the Generalised System of Preferences (GSP/GSP+), continue to shape the current

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African trade landscape (see Figure 10). They offer African countries free trade access and tariff reductions to EU markets but reveal historical asymmetries in trade relations and agreements. There are 4 main trade agreements between the Africa-EU:

1. **EPA:** Economic Partnership Agreements
2. **GSP/GSP+:** Generalised System of Preferences
3. **EBA:** Economic Partnership Agreements
4. **AA:** Association Agreement

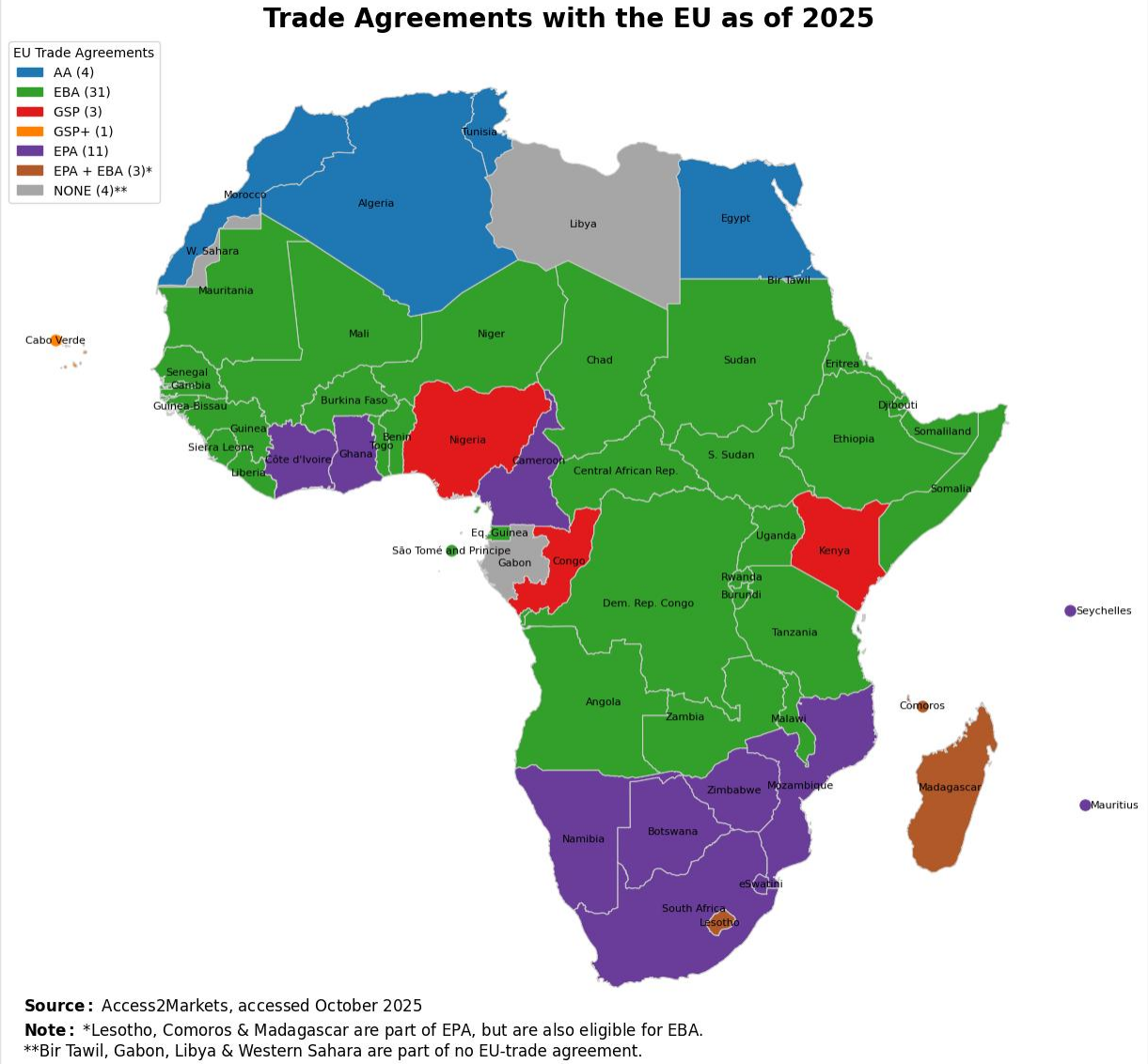
An **Economic Partnership Agreements** (EPA) offers trade benefits in goods, providing free access or better trading terms to EU markets with zero duties & quotas on select agricultural products[3]. Its purpose is to facilitate and promote sustainable development using trade as a tool, offering flexible rules of origin, financial support in conjunction with duty – and quote-free access while considering the socio-economic circumstances. EPAs can therefore be seen as an agreement going beyond conventional free-trade agreements. Currently, 15 African countries have applied EPAs with the EU as of 2025. The **Generalised Scheme of Preferences** (GSP/GSP+[4]) removes tariffs and import duties from (most agricultural) products entering the European market and is meant for low and lower- middle income countries [30]. As of 2025, Congo, Kenya and Nigeria are part of the GSP (General), with Cape Verde being part of GSP+. UNs definition of LDCs (Least Developed Countries), allows African countries to fall under the GSP[5] and the EBA (**Everything But Arms**) trade agreement with the EU when eligible, offering similar benefits, but despite these potential benefits, uptake of EUs trade agreements among the African countries remain modest. Currently, **Everything But Arms** (EBA) is EU's most comprehensive trade preference for LDCs, covering 34 countries in Africa as of 2025. The EBA removes import duties from all products destined for the EU, with the exception of arms and ammunition. Finally, four **Association Agreements** (AAs) are in effect, offering a long-term political and economic partnership between the EU and the country in question. Morocco, Tunisia, Egypt and Algeria benefit from these free trade agreements, eliminating and reducing tariffs on agricultural goods while also covering political and development perspectives.

[3] Excl. sensitive products

[4] GSP+ is a special incentive arrangement implement 27 international conventions related to labour and human rights, environmental and climate protection, and good governance (Source: European Commission Trade EU).

[5] Governed by the World Trade Organization (WTO) and offered by the EU.

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Source: Access2Markets, accessed October 2025
Note: *Lesotho, Comoros & Madagascar are part of EPA, but are also eligible for EBA.
**Bir Tawil, Gabon, Libya & Western Sahara are part of no EU-trade agreement.

Figure 10: Trade Agreements EU-AU

Currently, the continent is involved in 47 **Regional Trade Agreements** (RTA), marking its 5th place compared to other global regions (see Figure 11). The largest RTA is currently the **Common Market for Eastern and Southern Africa** (COMESA), with 21 members. It is followed by the **Southern African Development Community** (SADC), with 16 members. RTAs in place with non-African partners are predominantly in collaboration with the EU, highlighting the importance of the Union.

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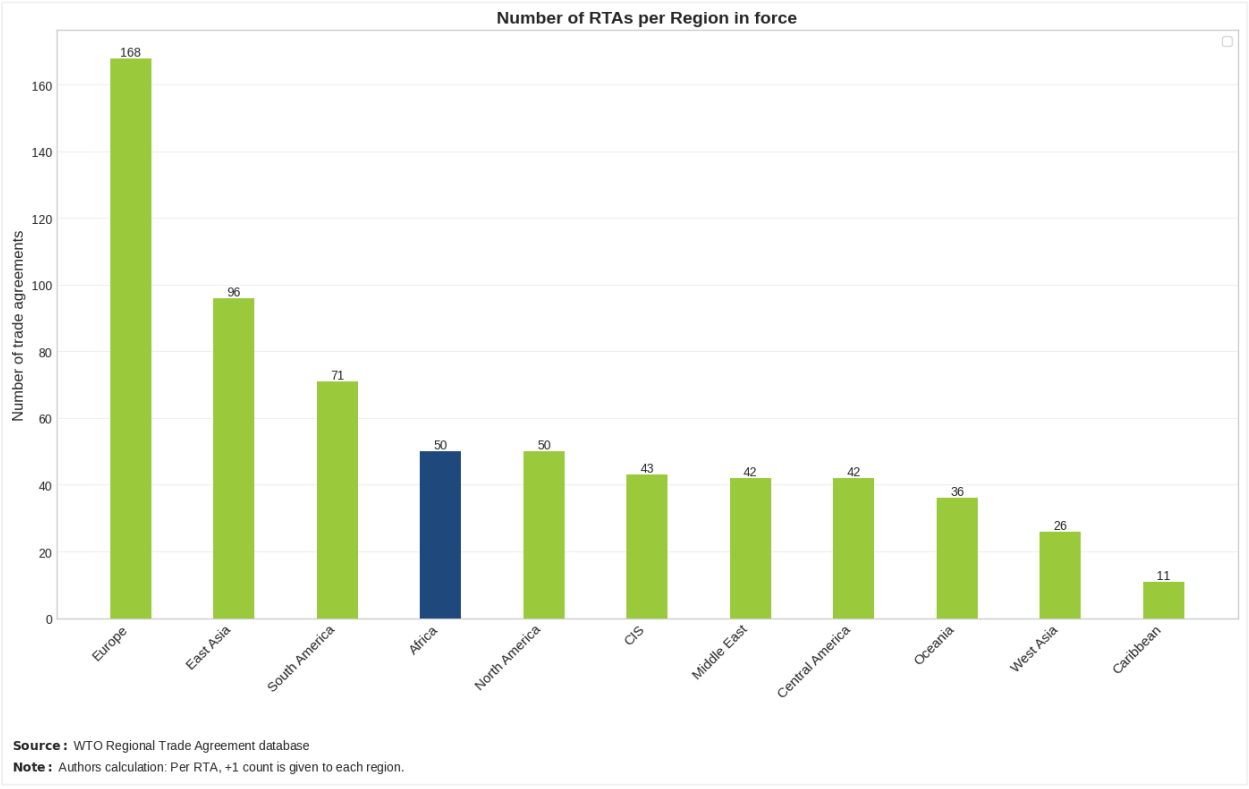


Figure 11: Number of RTAs in use globally [31]

With the creation of a single, liberalised market, resulting in one of the world's largest free trade areas, Africa's negotiating position on the world market is expected to improve significantly thanks to the AfCFTA. Intra-African trade should also benefit from the trade area with estimates showcasing a 53% increase in intra-African trade, leading to a potential shift from Africa's historically commodity-driven export nature to the creation of new markets, jobs and value-added opportunities [24], [25], [32]. With the creation of a single market of 1.3 billion people and a combined GDP of $3.4 trillion, the AfCFTA is also expected to create 14 million jobs, alleviate 50 million Africans out of poverty, increase cargo transports through African ports, and grow the manufacturer sector of Africa [25].

However, progress in implementing the AfCFTA has been slower than expected since its creation in 2018. Main reasons for its slow uptake have been a lack of infrastructure and political will to harmonise trade frameworks [25]. Nevertheless, 48 AU countries have ratified the AfCFTA as of 2025, with 19 officially published tariff schedules as of 2025. Despite its slow uptake among the contributing partners, the AfCFTA marks a consensus to create a unified market in which the AfCFTA plays a key role.

With Africa's aspiration for the future, outlined in Agenda 2063 [33], agriculture plays a pivotal role in the developments of the continent, which has seen drastic development changes with the **Comprehensive Africa Agriculture Development Program** in 2003 (CAADP) shifting agricultural from the fringes of development to countries' national strategy plans [34]. The CAADP is a pan-African framework, offering a set of principles and broadly defined strategies to assist African countries to review and assess their current situation. With renewed strengthening of CAADP through the Malabo Declaration in 2014, the CAADP framework has been incorporated within national agricultural development plans, focusing particularly on eliminating hunger, boosting agricultural productivity and aiding women and SMEs through the

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Agricultural Technical Vocational Education and Training program (ATVET). With the recent Kampala convention held in early 2025, a new strategy and action plan has been created, following the post-Malabo CAADP commitments. Further emphasis on reducing post-harvest losses by 50 percent, tripling of intra-African trade in agricultural products and increases the share of locally processed food to 35 percent of agrifood GDP, showcases renewed commitment of the CAADP [20], [35]. This commitment highlights the need for radical changes in view of Africa's growing population, current dependence on food imports, the effects of climate change on food production, and the transformation of the agricultural sector towards more value-added products. However, not all African countries have ratified the program, with 44 countries officially signing the CAADP and 39 countries having formal agricultural and food security investment plans as of the Malabo convention in 2014/2015. The renewed CAADP builds upon the Malabo and Kampala declarations, with a renewed strategy from 2026 till 2035, highlighting its importance for development strategies since the start in 2003.

The World Bank Group and the WTO in collaboration with the African Union launched a digital transformation strategy in 2019, named Digital Economy for Africa initiative (DE4A) [36]. This initiative supports the digital transformation strategy of the AU to transform the African economy and unlock new pathways for economic growth, innovation, job creation and access to services.

The DEA4A builds upon 4 foundational pillars to unfold Africa's digitalisation potential, namely (1) enabling a policy & regulatory environment, (2) digital infrastructure, (3) digital skill & human capacity and lastly, (4) digital innovation and entrepreneurship. It aims to ensure that every individual, business and government agency is digitally enabled by 2030, promoting the integration of digital technologies and solutions in various sectors of the African economy. To assess the status of the digital economy in a given country, five pillars of the DEA initiative[6] are utilised to investigate how these key levers drive the development of the digital economy in each country.

The United Nations Economic Commission for Africa (UNECA) launched in December 2020 the Regional Digital Trade Regulatory (RDTI) through the African Trade Policy Center (ATPC). The RDTI aims to understand and assess the readiness of African countries to engage in digital trade and e-commerce. The initiative has published reports and components related to digital trade issues, a digital trade integration index and a digital service trade restrictiveness index. See Chapter 3.4 – National Digital Trade Strategies and Performance for an overview of the RDTII and national digitalisation strategies per region.

Building on the developments in these trade agreements and commitments made by the AU, digitalisation in agriculture offers new opportunities to align with Africa's ambitions as outlined in Agenda 2063. These developments align with the African Union's Agenda 2063, the AfCFTA, and the Sustainable Development Goals, and outline a shared vision for a resilient, inclusive, and digitally enabled agri-food system.

[6] Digital infrastructure, digital public platforms, digital financial services, digital businesses, and digital skills.

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2.4. Current State of Inter-African and External Trade

The African continent plays a modest role in the global import and export of crops and agricultural products (see Figure 12). Agricultural development continues playing an important role in the continent's economy but only captures a small part of the value-added from its raw commodities, resulting in low agricultural value captured. This limited value capture is primarily caused by the export of raw commodities, failing to capture the processing or value-enhancing modifications made to agricultural products[7].

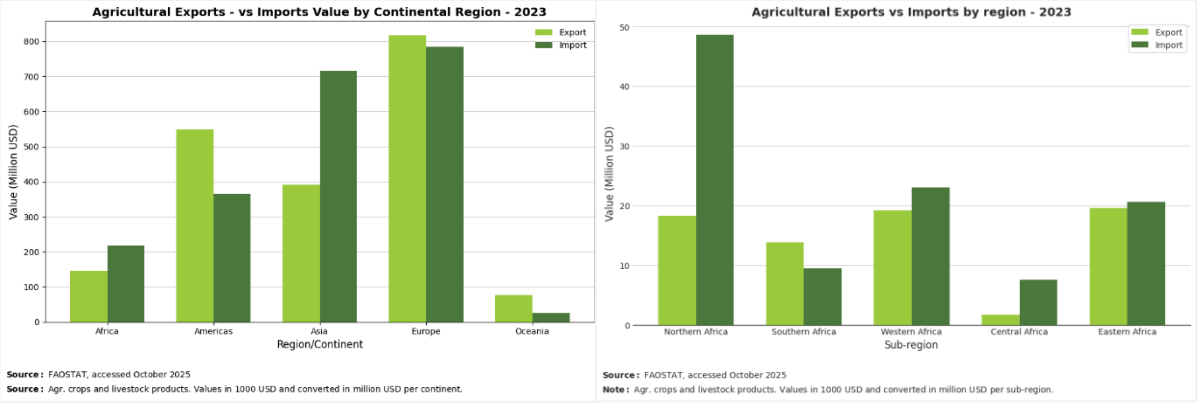


Figure 12: Agricultural Exports vs Imports globally and per African Region

Despite improvements in agricultural yields and food security, the continent remains heavily dependent on food imports from outside of Africa, with intra-African trade (of agricultural products) only spanning a small portion of the continent's total export. However, there are regional differences, with North African countries importing proportionally more agricultural products compared to the rest of the continent, given the limited arable land and water scarcity. The Southern region has a positive agricultural trade balance, with the Western and Eastern African countries having only a slight agricultural trade imbalance. Central Africa has a relatively large trade imbalance, comparable to the Northern region.

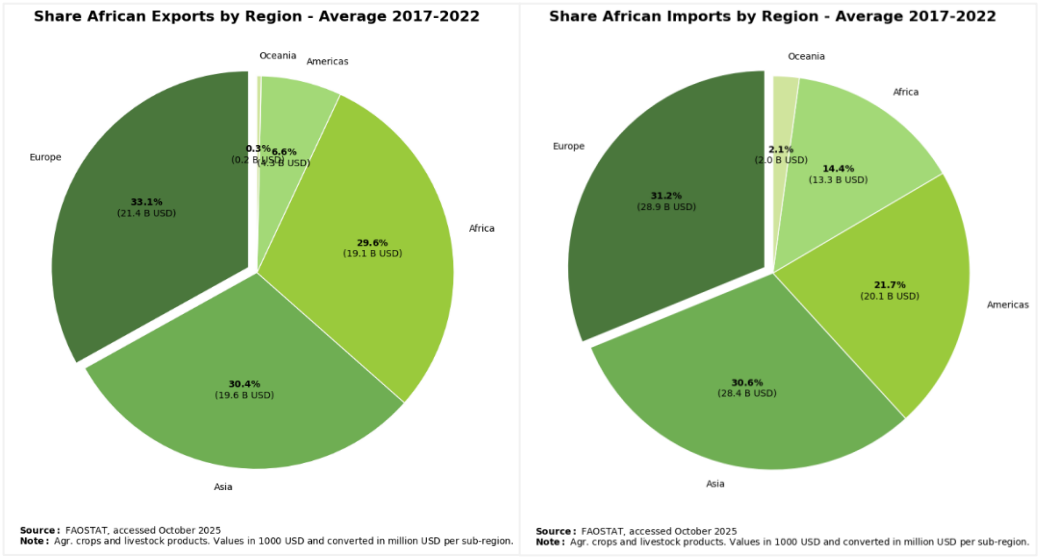


Figure 13: Share import/exports agricultural products per region

[7] Unfortunately, import & export quantity data wasn't available on agricultural food trade.

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The continent's international agricultural export trade is primarily driven towards Asia and the EU, highlighting the low dependence of intra-African trade between the countries (see Figure 13). Both continents are also important for Africa's food imports, accounting for roughly a third each of the continent's food import share. Additionally, the Americas still account for roughly 20% of the food imports, outclassing Africa's food imports from its own member states compared to the lower share of export to the Americas.

In line with the continent's ambition from the AfCFTA and CAADP to improve agricultural trade and incorporate more value-addition processes to the agricultural commodities the continent produces, the need for deeper integration with regional partners on agricultural trade, trade procedures, infrastructure and policy coordination are needed to ensure food security for the growing population.

It should be noted that the FAOSTAT database does contain limitations on data completeness, resulting in inconsistent reporting of trade data and may not fully capture international trade and informal trade.

2.5. Current State of Intra-African Agricultural Trade

2.5.1. Formal Trade

Insights into the current trends in intra-African trade showcases how the Southern region trades proportionally more of their agricultural exports with neighbouring African countries. Despite the large reliance on food imports in Northern Africa, intra-African export for these countries is only a small part of their agricultural exports share. Despite the small agricultural production capacity and population of Lesotho and Djibouti, the majority of their agricultural exports is destined for another African market (see Figure 14).

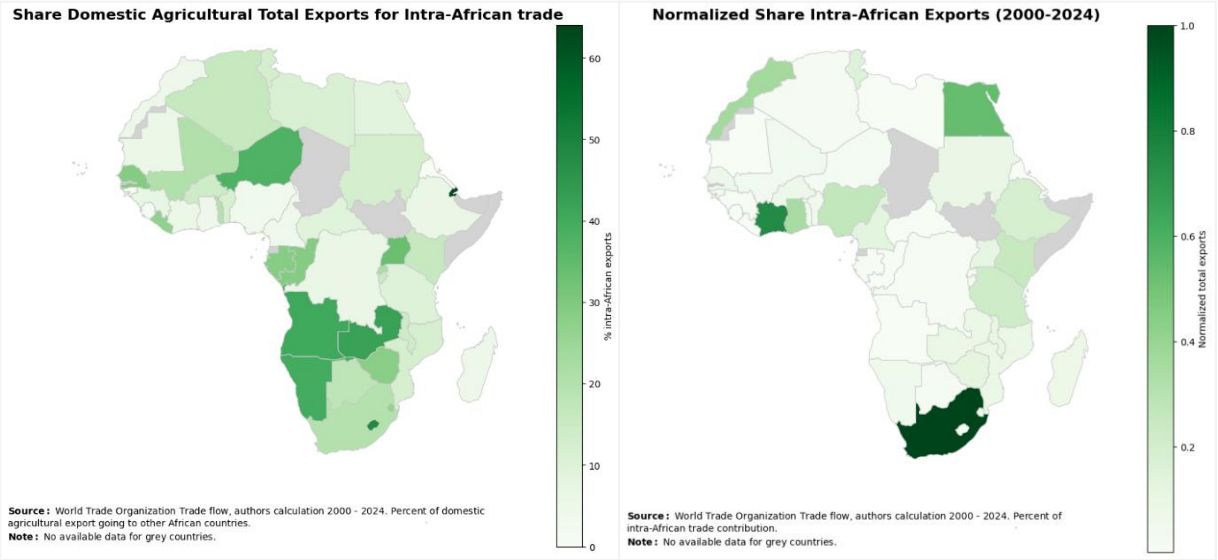


Figure 14: Share Intra-African Exports

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Comparing the total intra-African trade share, South Africa contributes the most to the intra-African agricultural trade with almost a third of the total between 2000 and 2024, followed by Sierra Leone, Egypt, Ghana, Morocco and Nigeria.

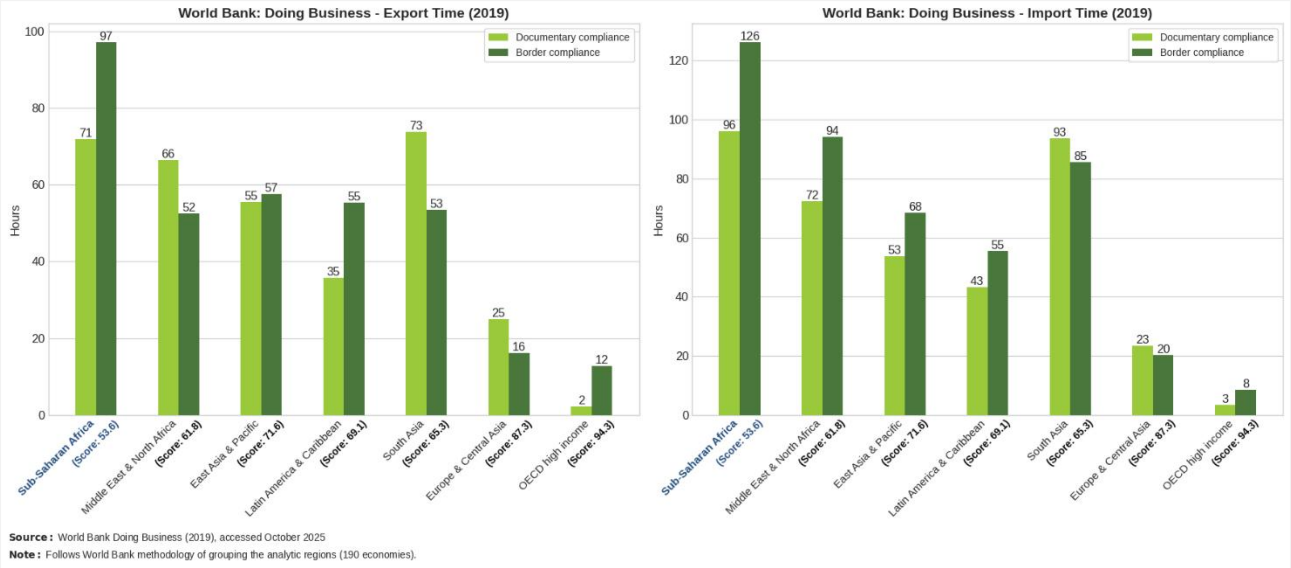


Figure 15: World Bank Doing Business: Time in days import/export

The World Bank offers an overview of the ease of doing business for a specific country, mapping across 10 key areas a country's regulatory environment, including trade procedures & compliances, business entry requirements, taxation and more. It offers a general overview to compare a country or region performance, allowing conclusions to be drawn about the impact of trade-related compliances and implications on businesses implications within that specific country's regulations.

According to the World Bank (as of 2019)[8], the Sub-Saharan region indicates a long lead time for importing – and exporting goods in terms of hours required for documentation purposes. Border compliance showcases a similar pattern across import/export, with 96 and 126 hours respectively (see Figure 15) [37]. A similar trend can be found in the compliance export time, with 71 hours for documentary compliance and 97 hours for border compliance respectively. Despite a quicker processing time relatively compared to imports, the duration creates delays and affects the efficiency and competitiveness of domestic producers, especially those dealing with highly perishable products.

The SSA region scores with 53.6 low on the Ease of Doing Business indicator, indicating that the region scores around 50 points away from the best regulatory performance across all economies and time. The long border and documentation requirements entail increasing transaction costs, impacting businesses negatively.

The MENA region is comparable to other global regions with the hours required for export border compliance. Documentation hours follow a similar trend to SSA and South Asia, taking relatively longer to complete compared to the border and documentation compliance for exporting goods with 66 and 52 hours respectively. Importing compliance are on pair with South Asia and take longer compared to exporting goods, with 72 hours documentary

[8] The WTO decided to discontinue the dataset (2019) in 2021, announcing a replacement: B-READY that aims to improve upon the original dataset by 2026. The following section displays the current published datasets of B-READY as of 2025.

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compliance and 94 border compliance hours respectively. This indicates relatively higher administrative and procedural burdens compared to export of goods from the region.

The region showcases a minor performance increase over SSA, scoring 61.8 on the Ease of Doing Business indicator. Nevertheless, the performance of both African regions indicate further strides must be made to lower the administrative and procedural burden for producers and exporters to reap the benefits of trade. Standardisation and electronic cross-border paperless trade are promising options to streamline the fragmented compliance landscape on the continent, lower transaction costs and minimising the administrative burden that impacts the supple chain efficiency of businesses engaged in international trade.

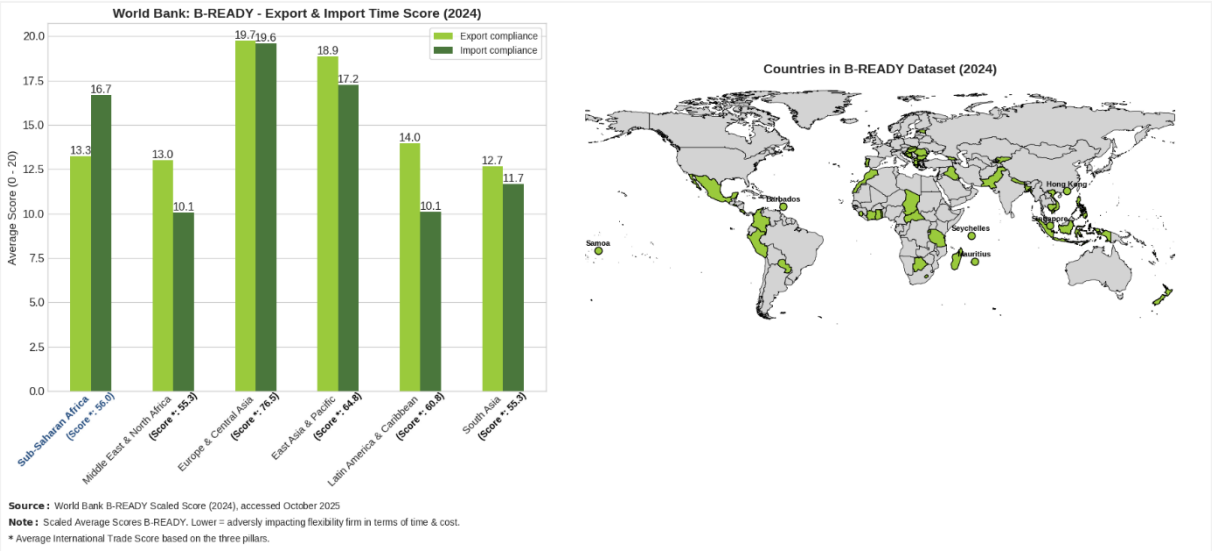


Figure 16: World Bank B-READY Trade Import & Export Compliance Scores. [38]

Progress is made on a renewed dataset of the Doing Business system from World Bank, which provides an updated assessment of the ease of doing business performance across economies. The revised dataset builds upon (methodological) criticism[9] of the previous 'doing business' assessment, and adds a broader view, with the inclusion of measuring social inclusion, environmental sustainability and public service delivery.

The World Bank dataset has published the first results of the renewed Doing Business (B-READY) dataset for the first 50 economies (see Figure 16), providing a partial view of the regions performance. SSA scores relatively better in the export and import compliance (time & cost) compared to the MENA region, showcasing a shifting trend compared to the 2019 Doing Business dataset. The SSA region (consisting of countries primarily in Western, Central and Eastern Africa in B-READY 2024) has seen a positive shift in import compliance performance, with a score of 16.7 outperforming every region except for EU & Asia. Export compliance in both SSA and MENA region performs similarly, showcasing improvements compared to their 2019 results, but lagging behind the global leaders. Although both regions showcase improvements in trade compliance, with the subset of SSA countries particularly

[9] Both methodologies of the Word Bank are criticised for its methodology, being cited as offering a narrow view of what constitutes to a healthy and economic system. However, the renewed B-READY introduces greater transparency and expands the availability of public data, but the results should still be interpreted with caution.

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indicating strong improvement relatively to their 2019 standings, trade compliance requirements continue to impact producers and exporters with significant costs and delays.

2.5.2. Informal trade

Informal trade represents a central component of agricultural value creation in many African countries. It is not a marginal or residual phenomenon, but a dominant, socially embedded and economically functional system. This has long been observed in classical economic and anthropological literature [39], [40], [41] and is reinforced by more recent ethnographic studies, including empirical fieldwork in Ghana demonstrating how informal markets are rooted in social networks, moral obligations and everyday livelihood strategies [42].

Informal markets operate on the basis of trust, reputation, personal networks, and continuous negotiation. Prices, quantities and qualities are rarely standardised but determined situationally. This allows for flexibility and high adaptability – key advantages in volatile agrifood systems. Information flows predominantly through oral channels, personal networks, phone calls, and increasingly WhatsApp, a pattern clearly reflected in the STREAMING Survey [43].

The digital landscape in these contexts is therefore shaped less by formally established platforms and more by hybrid practices: basic mobile communication, selective use of smartphones, informal digital payments, and minimal engagement with standardised identification or traceability systems. Surveyed actors frequently report limited access to digital tools, low perceived usefulness, linguistic barriers, and inadequate infrastructure [43]. Digital systems are often viewed as labour-intensive, difficult to understand, or misaligned with existing routines.

At the same time, informal markets fulfil essential governance functions. Classic theories of situated knowledge and local steering help explain why informal markets in West Africa function reliably despite limited formal regulatory structures [44]. Local institutions, social norms and informal authorities substitute or complement state regulation – an arrangement described in detail in ethnographic analyses [42].

Women play a central role within this system. Female traders organise logistics, storage, price comparisons and information exchange, and they are critical to local food security. Yet the digital landscape reveals that women face reduced access to digital devices, training and registered systems – posing a significant risk of digital exclusion and representing a core challenge for future standardisation efforts [43].

Overall, the digital landscape within informal trade is structured less by technology and more by social practice. Digital solutions can only succeed if they:

- build on existing communication practices (oral exchange, WhatsApp, face-to-face),
- are low-cost and robust,
- require minimal digital literacy,
- incorporate gender considerations, and
- integrate flexibly into existing social and economic routines.

Digital standards must therefore be conceived as “socially embedded” innovations – tools that complement, rather than replace, informal practices. Only with such alignment can

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digitalisation scale within informal agrifood value chains and contribute to improved traceability, transparency and market access.

2.6. Digital Transformation in African Food Systems

The African continent is developing at a rapid pace across economic and social dimensions, with technology adoption and transformation showcasing impressive uptake. A recent report of GSMA on the mobile economy in Africa reported mobile phone subscribers and connectivity among the population reaching 47% as of 2025, with predictions reaching 915 million mobile (53%) subscribers by 2030 [45]. These are impressive numbers from just 2.1% internet users in 2005 [8]. This uptake in unique mobile subscribers offers not only pathways of access to digital tools and solutions that benefits the entirety of the African economy, but also offer benefits to smallholder farmers, who often are in remote locations with limited connectivity.

Digitalisation in the agri-food (D4Ag) sector offers, with the use of digital technologies, opportunities to improve productivity, yield rates of crops, efficiency, and sustainability [28]. D4Ag offer digital information and services, reshaping farmers' long-held understanding and beliefs of rural farming, and affects activities and sub-practices such as planning, preparation, planting, fertilizing, harvesting, husbandry activities, sales and judgements of good agricultural practices [46].

Digitalisation in the agricultural sector can therefore be divided into three general categories; **Value Chain Digitalisation**, offering digital solutions and tools to primary agricultural stakeholders during and after the production of agricultural products, while **Trade & Market Digitalisation** incorporates standardisation methods and technologies that streamline documentation, logistics, certification and access to domestic and international markets. The recent emergence of agrotechnology is primarily digital based that share four key drivers: (1) low-cost & effective connectivity, (2) adaptable and affordability (tools), (3) advances in data analytics and sharing and (4) increasing demand agricultural sector [47].

Digital solutions, including both on-farm digitalisation and trade & market digitalisation in the agricultural sector can be summarised in the following concepts [28], [48], [49]:

1. **Digital Financial services**; access to credit, mobile money, bank payments/loans
2. **Digital Farm management tools**; inventory tracking, financial management, crop planning, weather forecasts, irrigation
3. **Digital Marketing**; market price information (AMIS), market access
4. **Digital Extension services**; digital advisory tools/services
5. **Supply Chain Management**; ERP systems & traceability tools
6. **Sustainability**; Integrate farm, market, and environmental data to help farmers make better decisions and comply with sustainability standards.

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Further mechanisation in agriculture with the addition of physical hardware, ranging from RFID sensors, drones and IoT devices, go hand-in-hand with data-driven software solutions. These technologies enable precision agriculture, streamlining the use of inputs with tools that enable monitoring of soil and crops health, increasing yields and reduce post-harvest losses [47]. More in-depth information can be found in Chapter 4 .

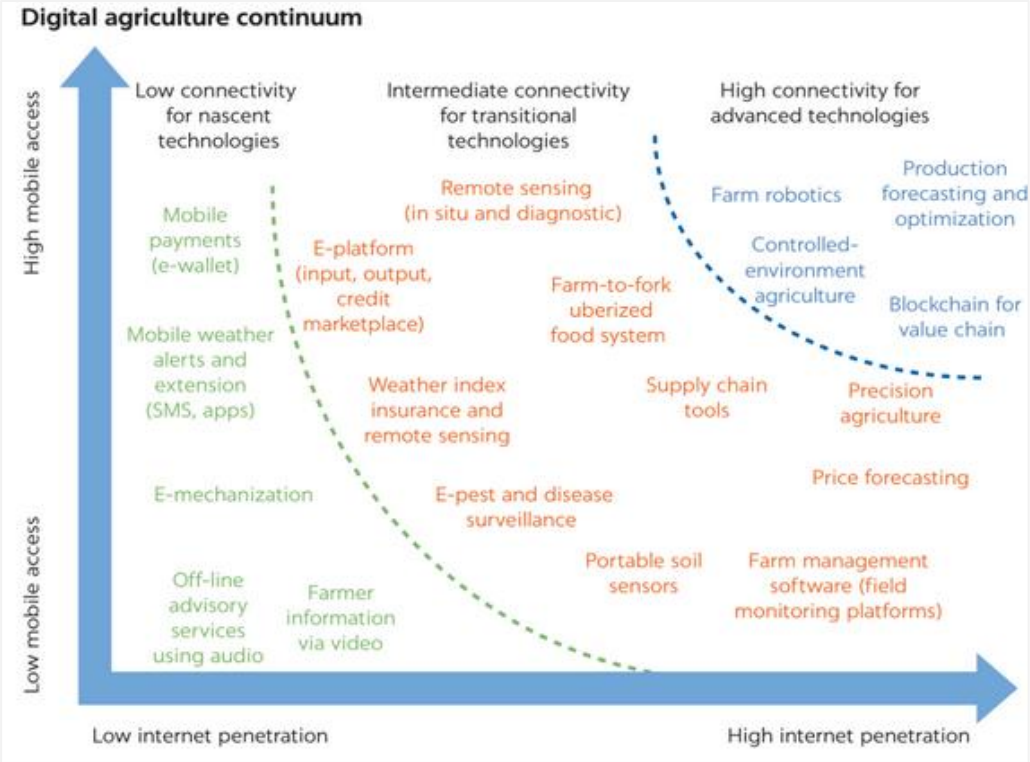


Figure 17: Agricultural Technologies - mobile access & internet penetration (Source: J. Kim et al. 2020 World Bank, Figure 2.5) [47]

Figure 17 showcases the mobile access and internet requirements for agricultural technologies from the World Bank DAT database, highlighting how advanced technologies require more accessibility and internet penetration compared to mobile money and extension services [47].

There is a growing interest in scaling up digital agriculture across the African Union. The African agricultural sector is expected to be a three trillion-dollar market by 2030, offering opportunities to drive innovation and efficiency to improve yield productivity and income to the actors in the chain. Both intra- and inter-African agriculture trade is a contributing factor for generating value-addition practices in the supply chain. The AfCFTA has deployed several initiatives to strengthen trade infrastructure and transparency across the AU. Notable tools include **The African Trade Observatory** (ATO), one of the five operational instruments of the AfCFTA, which provides real-time trade date to enhance policymaking and support intra-African trade. Additionally, the AfCFTA's Non-Tariff Barriers, an online reporting & monitoring tool allows all African business sectors to report any obstacles encountered when trading across intra-African borders.

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2.7. Conclusion

1. What is the current state of Africa's food systems, agricultural trade, and agreements?

Chapter 2 highlighted the current state of Africa's food systems, agricultural trade and trade-related agreements, highlighting current practices, commitments and external challenges the continent is facing. Agriculture in Africa remains crucial for ensuring food security and economic growth, employing a large part of the population and is expected to grow to a 3 trillion-dollar sector by 2030. However, low value additions, limited yields per hectare and a strong (regional) reliance on food imports outside Africa, especially in the Northern region, hinder the sector's growth. The expected population increase, reliance on food imports and the effects of climate change showcase the external challenges and the importance of building resilient agricultural food systems to ensure sustainable economic development. While trade agreements with the EU remain modest, the AfCFTA present significant opportunities to boost intra-African trade, falling in line with the continent's commitments in Agenda 2063. Continental initiatives such as AfCFTA, CAADP, and DEA4A offer frameworks and governmental assistance to provide practical uptake among AU member states to strengthen digitalisation, triple intra-African trade, and remove trade barriers, offering uniform market access to African countries. The adoption of digital innovative technologies, such as mobile platforms & market information systems for the agricultural sector, underlines the current technological uptake and offers new opportunities to address the challenges the sector is facing, bringing socio-technical transformation opportunities that fall in line with the continent's commitments.

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3. State Digital Infrastructure supporting Agricultural Trade

Chapter 3 provides an overview of the current state of digital infrastructure and the role of digitalisation for trade facilitation in the African agricultural sector. The chapter also provides a detailed overview of Africa-EU trade requirements (documentations, food safety regulations, agreements) and regulatory trade performance in Africa and the role of the formal and informal sector. It draws insights from desk research, Policy & Regulatory framework analysis, Trade & Digitalisation datasets and findings form case studies. This chapter addresses research questions:

2.	Which regulatory frameworks currently support digital agricultural trade, and how do they support cross-border paperless trade?
3.	How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?

Connectivity, digital agri-food strategies and digital trade practices - supporting cross-border trade - across the continent have made great strides in recent years, with mobile internet connectivity uptake remaining a key driver of existing agricultural digital solutions and their benefits. However, there remains a high usage gap, and inconsistent, fragmented, (regulatory) implementation, hindering full realization of digital transformation benefits.

3.1. Mobile Connectivity and Digital Solutions for African Agriculture

The continent has made great strides on their digital infrastructure in recent years. A big part of improved connectivity among the African landscape consists of mobile coverage and adoption. Adoption of mobile phones and the number of connected users are showcasing a steady rise [45]. As of 2024, there are roughly 416 million (28%) connected users, which highlights that further strides need to be made to provide connectivity to the remaining 72% of the population. Nevertheless, the benefits of the increased connectivity already resulted in more revenues & investments, increased jobs, contribution to public funding and contributes to about 7.7% of the continent's GDP. The mobile infrastructure already covers 92% of the continent, offering the population access to the internet. However, Africa falls especially behind in mobile internet penetration rate compared to other global regions (see Figure 18), utilising only 44% of the existing usage potential [50].

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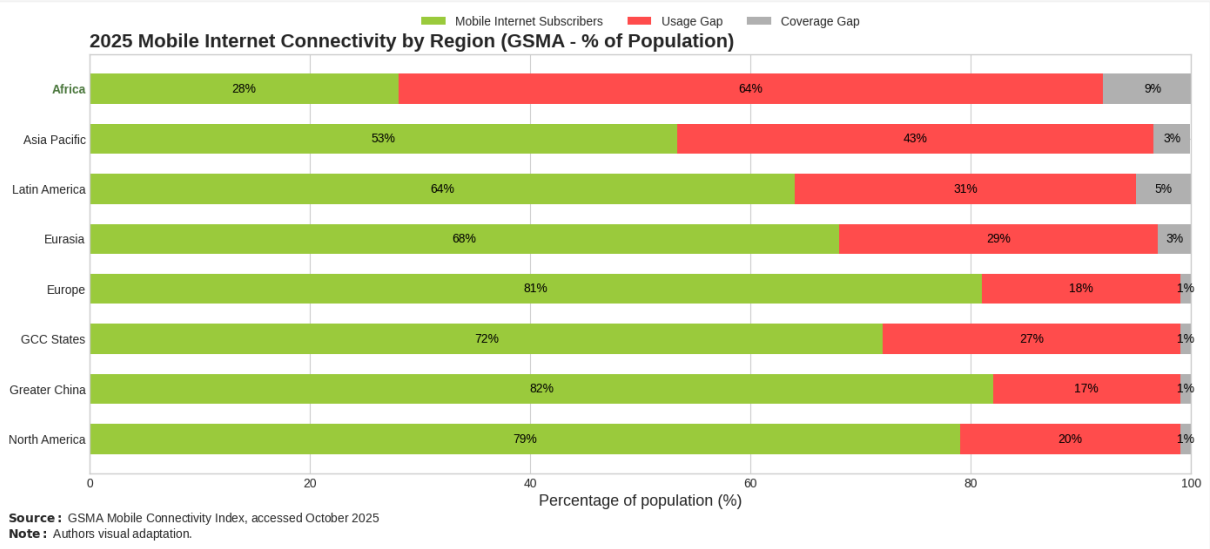


Figure 18: Mobile internet connectivity

From an agricultural perspective, mobile phones connectivity provides complementary benefits to the agricultural value chain, with important digital services now becoming available to (remote) smallholder farmers. Examples of digital services are (1) **digital farm management** systems offering inventory tracking, weather information and irrigation management, (2) **digital extension services** offering knowledge, training and support to farmers, (3) **digital financial services and goods** such as mobile money, investment options and financial advice, (4) **digital marketing services**, marketing-related tools for agricultural products, (5) **supply chain management** – digital tools to streamline logistics, shipping, traceability and more. These services offer market access and information to farmers, provide knowledge to improve production yields and improve crop rotation and opens new financial inclusion by mobile money and availability of investment options and (6) **sustainability** offering ecosystem support tools to integrate farm, market and environmental data to support farmers to comply with sustainability standards. It should be noted that in addition to mobile phones, additional hardware (printers for labelling and monitors or computers for data entry/analysis) is often needed to properly utilise the functionalities of these digital tools and services. From a usability perspective, supply chain management tools require larger screens to conveniently enter data and display effective dashboard analysis. Similarly, digital farm management systems are in general difficult to operate solely on mobile devices, given that core functionalities (label printing, barcode scanners, desktop interface) still require extra hardware beyond a (smart) phone. Nevertheless, design considerations that fit the local landscape in Africa could provide mobile-friendly useability solutions to mitigate potential barriers to adoption.

Further downstream the supply chain, digital traceability systems play a major role in trade-related instances, offering compliance with (international) standards regarding food safety, quality, logging of goods as well as complying with shipping documentation.

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3.2. Role of Digitalisation in Trade Facilitation

To map the current state of digitalisation, with a particular focus on global (digital) standards to align with the harmonisation of the AU food trade system, a brief introduction will be given of the role of digitalisation for trade facilitation in **Agricultural Value Chains** (AVC). Following the introduction of AVCs, a general overview of certificates and customs documentations required for agricultural trade is given, with a particular focus on EU-specific documentation and its link to potential improvements for standardising the African agricultural trade market.

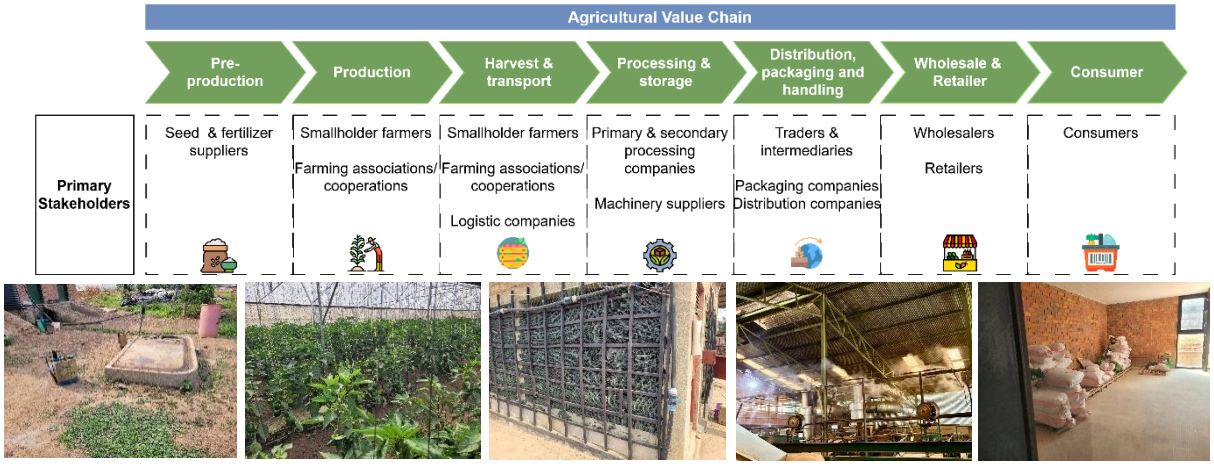


Figure 19: Agricultural Value Chain (Rwandan tea, horticulture and coffee producer, captured during a field trip to Rwanda, 2025 - own illustration)

A typical AVC from farm to fork consists of several main processes with multiple stakeholders involved (see Figure 19). For the African AVG, the primary producer consists mainly of smallholder farmers who often are part of a farming association that offer access to shared resources, materials and training. The produce after harvest is transported to processing & storage facilities, often in possession of farming cooperations, where the goods are destined for either auction-based markets, such as the Mombasa Tea Auction in Kenya in the case of tea or sold to traders and intermediaries directly. Smallholder farmers working for a cooperation are generally paid monthly on the volume or weight of goods they deliver from the farm owned by the cooperative they work for.

In case of traders and intermediaries, the goods often end up on local markets (both formal or informal in case of absence of local regulations) where the goods are sold through local traders directly to the customer. In case of auction-based processes, exporters and logistic firms often purchase produce via these auctions through export agents. Freight forwards and shipping brokers ensure the goods are transported to the final (international) markets. The goods end up at a local distributor or warehouse where it is often repackaged to consumer units and to comply with local regulations and labelling requirements before reaching supermarket shelves.

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Throughout the AVC, data collection of the produce plays a pivotal role in complying with international standards required for agricultural trade, enabling cross-border paperless trade. Typical data collection in an AVC consists of quality assurance, traceability and food safety (sanitary and phytosanitary certification) information, which in turn document the origin, processing and handling of the goods – a requirement for customs clearance at the border. Certificates and custom documentation required for trade, both intra- and inter-African, typically consists of (see Figure 20) [51]:

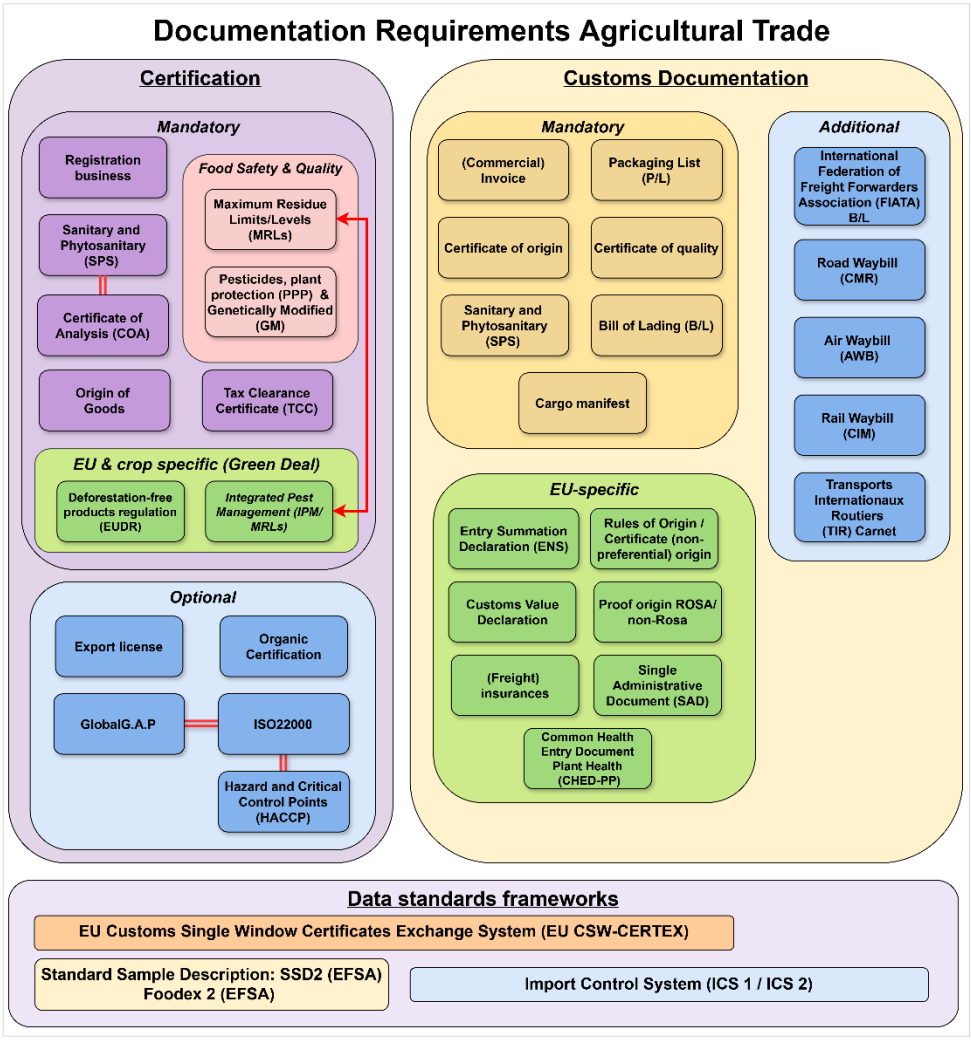


Figure 20: Documentation requirements agricultural intra/inter-African trade (own illustration) [51]

1. **Registration certificates** of the business, including investment, taxes and other legal certificates issued in the company's country of origin.
2. **Export licenses** in case of cross-border trade - issued by the domestic authority in charge of trade-related matters.
3. **Certificates of Origin and Quality** – a mandatory requirement at customs to identify the production locations of the goods and assessments of product standards related to quality and food safety.
4. **Sanitary and phytosanitary (SPS)** certificates, application of food safety and animal/plant health regulations[10].

[10] Each importing country has different requirements, with the World Trade Organization (WTO) issuing standardised SPS frameworks and science-based requirements.

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5. Mandatory **customs documentation**, consisting of a commercial invoice, packaging list, bill of lading and the previous mentioned certificates.
6. Sharing of relevant further Business-to-Business (B2B) information accompanying the physical goods flow, e.g. regarding facility and product master data as well as transactional data of shipping (receiving, storage, goods handling, transport, sales).

The required documentation and certificates can differ based on the type of crop and the country of origin issuing the domestic legal documents. However, the above captures the general requirements from both perspectives and should be adjusted for individual cases, crops and geographical regions.

Trade between Africa and the EU require additional specific documentations, particularly regarding environmental regulations and food standards & safety. Current EU regulation on pesticides usage (Maximum Residue Levels MRLs) and Genetically Modified Organisms (GMOs) is complemented by two new initiatives under the Green Deal [52], [53]. Specifically, the EU Deforestation-free Regulation which entered in effect on June 29, 2023, and the Integrated Pest Management, demand further documentation on agricultural crop production practices. The EUDR aims to provide additional documentation demonstrating that agricultural goods[11] entering the EU markets are free from deforestation and forest degradation [53]. Micro, and small enterprises must comply with these new EUDR rules from June 30, 2026 and onwards. The EUDR does contain simpler rules for SMEs, consisting of lighter mitigation measures and simpler reporting obligations of their due diligence. Upstream suppliers putting the commodity or derivatives on the market are obligated to declare the full due diligence documentation. SMEs are exempt from the requirement to submit the (duplicate) documentation, alleviating the required work for the EUDR. IPM is not currently enforced for foreign farmers, but it is expected to become the de facto standard in the coming years.

Alongside the upcoming EUDR & IPM requirements, the EU requires additional customs documentation when goods are entering the EU.
To start with, the **Entry Summation Declaration (ENS)** contains advanced cargo information and is required at the customs office where the goods are first entering the EU [54]. The ENS allows customs to conduct a risk analysis for safety and security purposes before the goods are physically unloaded or cleared in its destination market. Next to an ENS, the EU also requires additional documentation on the rules & certificates of origin, consisting of *Registered Exporter System (REX)* & plant-health certification alongside insurance – and value declaration documentation. The EU does offer the **Single Administrative Document (SAD)** – a form used to simplify declaring import/export or transit declarations through one main customs form accepted by all EU member states [55].
Data exchange among business partners can be divided into three different kinds:

- **Master data**: source of common business data used for all systems, applications, and processes of an entire company.
- **Transactional data**: recorded as a result of business transactions (like order, invoice and dispatch advice), e.g., upon completion of a transfer of ownership, and
- **Visibility event data**: records of the completion of business process steps involving physical or digital entities. Each event captures which objects and subjects participated in

[11] The EUDR covers palm oil, cattle, soy, coffee, cocoa, timber and rubber, including derivates such as beef and chocolate.

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the process, when the process took place, where the objects were and will be afterward, and why (i.e., in what business context the process occurred).

While the AfCFTA does aim to simplify the required certifications and documentations for intra-African trade through its AfCFTA Rules of Origin & Certificate of Origin revisions, it does not yet provide a single, union-wide customs form similar to EUs SAD. It highlights the importance of interoperable data exchange mechanisms for effective trade facilitation, particularly the upcoming documentation requirement (Green Deal) for Africa-EU trade.

3.3. Institutional and Regulatory Frameworks Supporting Digitalisation in Agricultural Trade

3.3.1. Role and objective of CAADP

> *"Innovations like precision agriculture, digital tools, AI, and biotechnology. These technologies improve productivity, efficiency, and climate resilience, while promoting inclusive growth by benefiting smallholder farmers, women, and youth. By enhancing resource management and market access, technology is vital for building sustainable agri-food system. "*
>
> **Source: CAADP Strategy and Action Plan: 2026-2035** [56]

The CAADP and AfCFTA initiatives contain several agreements on utilising standardisation through eliminating NTBs and incorporating digitalisation methods to boost agricultural trade. Both initiatives contain elaborate frameworks on the role of digitalisation to reach *"Sustainable and Resilient Agrifood Systems for a Healthy and Prosperous Africa".* With the third edition of the CAADP, strategic objective *1 (SO): Intensifying sustainable food production, agro-industralisation, and trade* mention several key action areas to adopt digital solutions. Specifically, strengthening extension services and adoption of sustainable agricultural practices highlight a need for increasing access to and use of digital tools that communicate and facilitate the required knowledge of transforming the agrifood system. The CAADP defines digitalisation in agriculture/trade as:

The key areas mentioned in **SO1** are **boosting technical infrastructure and expertise** on emerging technologies (AI, precision agriculture, biotechnology) which indicates the role of further digitalisation in the sector, incorporating new technologies and methods to boost agricultural production**. Agro-Industralisation** through **building frameworks** that develop technologies and facilitate adoption and sharing of technical knowledge is a key action area focusing on SMEs in the food sector. Strengthening **market access** and **trade facilitation** through, among other things, digital trade systems and market access tools.

SO2: *Boosting Investment and Financing for Accelerated Agrifood Systems Transformation*, highlights the need to increase investments in agrifood technologies (energy, water, and irrigation: on-farm digitalisation) by among other things, incorporating mobile money and digitalised finance options. With the impressive adoption rate of mobile phones and network coverage (4G/5G) in Africa these last couple of years according to GSMA, a large part of the payment methods across the continent utilises a digital mobile finance option, linking a resident's identity to a SIM card that facilitates a bank account where money can be easily transferred or withdrawn from.

SO3: *Ensuring Food and Nutrition Security*, among diversification and cultivating diverse crops, places a big emphasis on **advancing agricultural extension services and programs**

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to improve food Q&S, with standardising SPS standards in one general protocol to improve efficiency, traceability, comparability across countries and crops. Uniformity and standardising health-related protocols with national food safety authorities (fast-track Africa Food Safety Agency).

SO4: *Advancing Inclusivity and Equitable livelihoods* addresses the need for improvement in **countries' infrastructure** (both soft and hard infrastructure) and emphasises the further development needed on creation of more digital ICT services. A specific focus on ensuring equitable access to ICT for women, youth and marginalised groups, whereby digital technologies are utilised to facilitate labour-saving and offer climate-smart technologies.

SO5: *Building Resilient Food Systems*, focuses on **promoting investments** in precision agricultural technologies, including AI, geospatial solutions and climate-smart technologies. It aims to equip farmers with digital technologies to manage risk, offer access to necessary knowledge and resources, including local knowledge, to promote investments that transform the agricultural industry into sustainable and resilient food systems. Specific examples of agricultural technologies mentioned in SO5 are solar-powered irrigation systems and incorporating other renewable energy sources, such as hydro gas. On top of that, a big emphasis is given again to improving and extending agricultural extension services, aimed at bringing the necessary knowledge and resources required to the farmers that are at the forefront of incorporating these technologies.

State parties pledge to allocate 10% of their national budget to agricultural development, aiming to achieve at least a 6% growth in GDP. However, results from the Malabo Declaration (2014 – 2025) indicate that fewer countries hit the annual expected budget allocation, with Burundi highlighting that despite the 10% allocation, the expected 6% growth seems to be infeasible with funding alone [57]. With the renewed Kampala CAADP agenda, a shift in the execution of the commitments is in place, building upon the 2003 Maputo declaration and the 2014 Malabo Declaration. Previous commitments emphasised agricultural production growth, whereas the Kampala declaration targets a broader perspective of agrifood-systems and its corresponding processes such as trade, value-addition and nutrition. The push towards economic transformation through the African backbone of agriculture highlights the push from its previous agricultural productivity & food security towards modern(ising), industrialised agrifood system with envisions of sustainability and resilience in its commitments [20], [56], [58], [59].

Investments in agricultural extension service, promoting technology and innovation among SMEs and young entrepreneurs, as well as improving policies and creating enabling environments to permit technology and market developments and access. Education plays an import role in achieving and fulfilling resilient food systems. The CAADP addresses this through strengthening science, technology, engineering, and mathematics education at the primary, secondary, and tertiary levels to train the next generation of scientists, researchers, and tech-savvy farmers and value chain actors. In conjunction with the educational plans, the CAADP aims to ensure each country develops a critical mass of graduates in geospatial data, artificial intelligence and emerging technologies. Finally, emerging knowledge on global agrifood systems transformation should be leveraged through structured guidance and support systems by experts in the field and should be considered as a key requirement moving forward. Underlying these objectives to track the objectives and inform policy makers is the continuously

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improvement to data collection and quality as well as analytics methods through CAADP's monitoring and evaluation (M&E) system.

3.3.2. Role and objective of AfCFTA

> *"Digitally enabled transactions of trade in goods and services that can either be digitally or physically delivered, and that involve natural and juridical persons. "*
>
> **Source: AfCFTA Digital Trade Protocol 2024** [60]

The AfCFTA considers digitalisation in agriculture and trade a key priority. In February 2024, the **AfCFTA Digital Trade Protocol (DTP)** has been adopted by state parties, marking the start of the integration and standardisation of trade practices and requirements.

The COVID-19 pandemic forced state parties to rapidly update their customs procedures on digital payments and documentation. However, still to this day, many lack protocols and regulatory frameworks that enable digitalisation in these customs procedures. Currently 41 African countries (76%) have dedicated data protection laws, with 46 (85%) also containing cybersecurity laws. Consumer protection laws are only present in 23 (43%) countries, highlighting that the continent still has ground to make up [61].

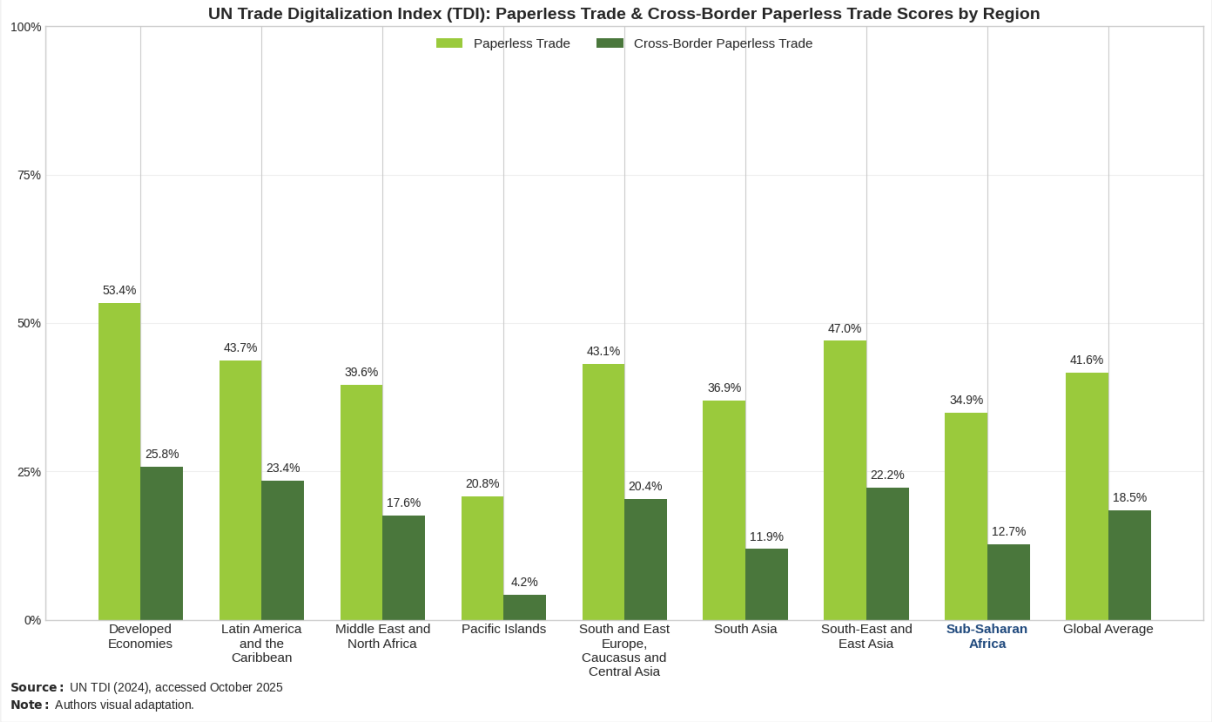


Figure 21: Current trade digitalisation implementation practices between regions [63]

From a business perspective, the lack of digitally enabled trade and the fragmented landscape of customs procedures and protocols result in slow and long lead times of goods, resulting in potential higher (transaction) costs and thus missed trade opportunities [62]. The Sub-Saharan region currently has 35% of paperless trade[12] domestically - an indicator how streamlined the trade procedures are with 13% being cross-border paperless trade (see Figure 21) [10] [63]. These numbers show similarities to the MENA region and South Asia, indicating the big step still to be taken to transform the trade sector through digitalisation. The UN Trade Digitalisation Index (TDI) result highlight the regional differences of relatively low cross-border paperless

[12] "'paperless trade' entails the adoption of electronic formats, replacing traditional paper-based documentation systems, with the aim of expediting trade processes and reducing associated costs".

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trade implementation (max. of 25% in OECD economies), with better results in domestic implementation of paperless trade. Nevertheless, both SSA and the MENA region perform below the global average on this front. With the ambition of transforming the African trade sector through the AfCFTA, the Digital Trade Protocol aims to address these concerns through enabling a regulatory environment.

Specifically, it contains 52 articles divided across 11 parts, addressing a broad range of key items in digital trade facilitating, following models of similar advanced digital trade agreements[13] (see Tabel 1) [64], [65], [66].

Table 1: Topics and Key Areas AfCFTA DTP

Topics DTP	Contents
1. General provisions	Definitions, objectives and scope of application, right to regulate
2. Market access and treatment of digital products	Annex on rules of origin, customs duties and non-discrimination of digital products.
3. Facilitating digital trade	Electronic trust services, electronic authentication, paperless trading, logistics and last-mile delivery, electronic contracts, electronic invoicing, digital identities, digital payments, domestic electronic transactions framework, electronic transferable records, digital infrastructure, interoperability and mutual recognition.
4. Data governance	Cross-border data transfers, personal data protection, location computing facilities and data innovation.
5. Business and consumer trust	Source code, cybersecurity, internet access, online consumer protection, unsolicited commercial electronic communications and online safety & security.
6. Digital trade inclusion	Digital inclusion, participation of micro and SME, digital innovation and entrepreneurship and digital skills development.
7. Emerging technologies and innovation	Emerging and advanced technologies, financial technology and ICT.
8. Institutional arrangements	Digital Trade Committee
9. Transparency	Publication of information, open government information, notification and non-disclosure of confidential information.
10. Technical assistance capacity building and cooperation	Technical assistance and capacity building and areas of cooperation.
11. Final provisions	Relationship protocol with other agreements, such as the AfCFTA, dispute settlement, annex, entry into force, application, implementation and M&E, review and other miscellaneous items.

[13] Progressive Tran-Pacific Partnership Agreement (CPTTP), Digital Economy Partnership Agreement (DEPA), UK-Singapore Digital Economy Agreement (DEA)

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A notable example is topic 3: *Facilitating digital trade*, which addresses the previously mentioned structural issues Africa faces when it comes to trade facilitation. Specifically, the fragmented landscape of customs procedures, slowing down trade and increasing transaction costs. The DTP aims to unify these procedures through standardised protocols and frameworks, providing the necessary legal and regulations foundation to adopt and permit electronic authentication, for example, a necessary aspect of transforming into paperless trading and incorporating electronic contracts. The electronic invoices, transactions and digital payments that ensure cross-border interoperability marks an important step in the significant role the Pan-Africa Payment and Settlement Systems (PAPSS) can have on ensuring seamless financial integration across African countries. The extensive focus on digital transactions in the DTP can play a significant role in improving trust in digital transactions, a key area that plays a role in the slowdowns in the adoption of the PAPSS and the AfCFTA [26]. Additionally, the fragmented AU policy and regulatory environments affect implementation, slowing down the role of digital trade systems to achieve its full potential.

The DTP topics form an extensive foundation on which domestic African digital trade integration can be built, offering the required legal and institutional mechanisms for state parties to harmonise their digital regulations to improve and enable a unified African digital market. As of 2025, the DTP is currently not final, with several annexes still under negotiating. Its success is dependent on the adoption and implementation of the framework at a national level, with several structural challenges that might hinder the effectiveness of the protocol. Hindering might arise from the fragmented and unique challenges facing the African landscape, with enforcing obligations on domestic regulators. Although the DTP does allow flexibility through its implementation strategy, the absence of a general exceptions clause (legal safety net that permits specification deviations from obligations) further puts stress on the already abundance of sub-regional agreements. Further, the state parties must make big strides on the current gaps in regulation and infrastructure. Commitments focusing on domestic capacity building regarding data governance, interoperability, cybersecurity and digital skill and expertise development, are needed [26]. Nevertheless, the DTP is a bold forward-looking protocol that will test Africa's commitment towards its digital transformation goals. Its success will depend on the political will of the state parties involved to implement the framework, with required commitments to capacity-building to ensure rapid implementation.

3.4. National Digital Trade Strategies and Performance

At a domestic level, African countries are responsible for aligning their national agricultural and trade development programs with frameworks such as the AfCFTA and the CAADP. The two initiatives can be considered the main driving force of state members' agricultural development program. To offer an overview of the current state of the digital trade regulations and landscape before offering current examples of domestic agricultural development plans, the United Nations Economic and Social Commission for Africa (ECA) under the *ESCAP-ECA-ECLAC Regional Digital Trade Regulatory Integration Initiative*, published an extensive overview of the continent's digital trade policy environment. Comprising of mapping the cost associated with enhancing regulatory consistency through international and regional cooperation, the RDTII 2.0 utilises 12 pillars to evaluate the countries' performance on their regulatory environment affecting digital trade businesses [67]. Specifically, the 12 pillars can be clustered in three groups: (1) traditional trade policies, (2) other domestic policies and (3) digital governance

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clusters (see Annex III – Trade Integration Index 2.0 for a detailed breakdown of the 12 pillars). The scores are weighted averages of the indicator and provide comparative insights in:

- **Differential treatment** between domestic and foreign providers
- **Additional regulatory compliance costs to services provided online**, relative to those offered offline
- **Absence of certain international norms**, for example international agreement and legislation that are significant contributors of interoperability across countries/jurisdictions.

The normalised index scores represent the degree of restrictiveness in a country's regulatory environment, with a score of 0 indicating an optimal open digital trade environment with no significant barriers, and a score of 1 representing a very restrictive and de-harmonised regulatory environment. Countries that contain gaps in its regulations, by having it partially implemented, are not automatically included in the score, with the RDTII only assessing the presence of regulatory restrictiveness rather than completion of regulatory implementation.

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Figure 22: Digital Trade Regulatory Environment RDTII 2.0, (Source: UN – ESCAP - Figure 19) [68]

The RDTII 2.0 dataset covers digital trade – trade in goods and services delivered digitally or enabled by cross-border data flows – and includes the rules, legislation and digital services required to make digital trade possible, providing an overview on how digital trade measures either facilitate or restrict digital economic activity (see Annex III – Trade Regional Index 2.0 for a detailed overview of the RDTII 2.0 parameters). To complement the Regional Digital Trade Regulatory Environment, the UN Survey on Digital and Sustainable Trade Facilitation 2025 in section 3.4.1, showcases the status of practical implementation measures among the African countries.

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Compared to Asia-Pacific and Latin America and the Caribbean (LAC) region, the African continent performs at an intermediate level, with an average score of 0.34, positioned between Asia-Pacific (0.41) and LAC (0.25). However, there are strong regional differences, reflecting uneven progress across the region. Countries in North and Southern Africa demonstrate higher scores of regulatory maturities with international standards compared to the average Asia-Pacific region and LAC.

To compare the regional differences in Africa, **North African** countries have on average a more moderate to high restrictive digital trade environment, with more barriers and higher compliance costs for digital trade (see Figure 22) [68]. Egypt illustrates the most restrictive trade environment of the continent, scoring high among all twelve pillars. Mauritania contains a more open trade environment with less regulatory restrictions among the northern countries, with relatively high restrictions regarding tariffs and trade defence measures. However, the country showcases regulatory gaps on four out of the twelve pillars. **Southern African** countries score on average below the continent RDTII score, illustrating to have a more open digital trade environment. Lesotho scores the lowest of the 11 countries, containing a (low) score in nine out of the twelve pillars. Angola on the other hand faces a more restrictive trade regulatory environment, with relatively high scores on tariffs and cross-trade border data policies. A select set of **West African** countries perform above the regions trend, with Nigeria, Guinea and Côte d'Ivoire containing a more restrictive environment. Tariffs – and internet intermediary liability contributing the most to the high RDTII scores of the three countries. Mali and Côte d'Ivoire contain the lowest score despite Côte d'Ivoire scoring on all twelve pillars. Tariffs and trade defence contributing the most to the RDTII score of these 2 countries. **East Africa** with Djibouti, South Sudan and Ethiopia having a more restrictive digital trade environments of East Africa, scoring quite high on tariffs and trade defence measures, a common trend among the increasing restrictiveness of the African countries. Madagascar and Seychelles contain a more open digital trade environment. Finally, **Central Africa** performs close to the continent's average, with Sao Tomé and Principe falling below the continents trend**.** Cameroon and Gabon perform close to the continent's average, scoring well on tariffs and trade defence and standards and procedures.

The RDTII 2.0 results indicate in general a more permissive digital trade environment in Africa, albeit with large regional differences. Figure 23 from the UN-ESCAP report showcases the diversity among the African countries, by comparing the average pillar score with the level of policy similarity (calculated by the average values of inverse bilateral differences) [68].

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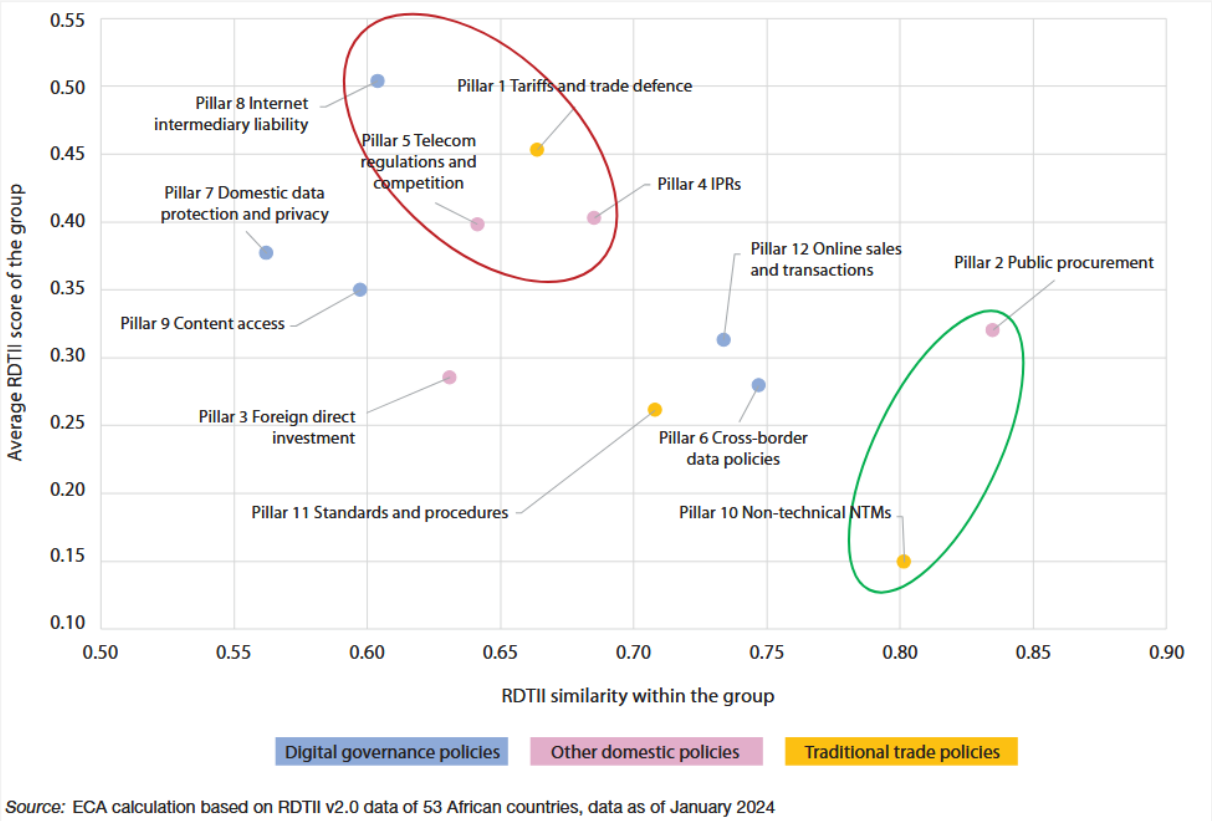


Figure 23: Digital trade policy differences in Africa 2023, RDTII 2.0 report (Source: UN-ESCAP - Figure 33) [68]

Notable differences include the high similarity and low RDTII score among non-technical NTMs (Pillar 10), indicating the absence of binding rules and gaps in the regulatory environment rather than high policy-induced cost. Standards and procedures (Pillar 11), cross-border data policies (Pillar 6), online sales (Pillar 12) and public procurement (Pillar 2) showcase a relatively high homogeneity. The low RDTII scores of these pillars indicate a rather non-restrictive environment. The lack of formal (trade-specific) commitments, such as multilateral trade agreements on cross-border data flows, WTO Government Procurement Agreement or adoption of internationally recognised frameworks on electronic commerce and signatures, restricts enabling of data flows, a fundamental aspect for facilitating digital trade. Governments should prioritise commitments and agreements towards cross-border and interoperability data flows.

Similar high RDTII values on regulations on tariffs and trade defence measures (Pillar 1), internet intermediary liability (Pillar 8), telecom regulation and competition (Pillar 5) and intellectual property rights (Pillar 4), indicates heavy regulations with a moderate level of heterogeneity among the countries.

High trade and tariffs regulation between the countries impede efficient trade relationships due to administrative burdens, high costs and market trade exclusion. Non-Tariff Measures are a key area of focus for Work Package 4 in the STREAMING consortium, which investigates the current state of NTFs across African countries, refining new modelling frameworks and generates policy recommendations to support alignment with the continent's commitments to improve intra-African and Africa-EU trade. Readers are encouraged to explore *T4.1 Mapping of Non-Tariff Barriers in the EU and Participating African Countries* for more detailed results.

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Emphasis on improving intellectual property rights and clear regulation on internet liability offers opportunities to improve protection and trust among businesses and customers with regards to digital services. The lack of adopted international copyright infringement agreements (e.g., World Intellectual Property Organization WIPO) may further compound this effect and should be addressed in policy initiatives moving forward. The telecom sector is heavily regulated among African countries, which limits the competitiveness, potentially having adverse effects regarding costs and access, hindering the digital adoption and development in the continent.

The relatively low foreign investment regulation (Pillar 3) score showcases in general an investment-friendly environment. However, the heterogeneity among the countries illustrates differences with regards to rules and burdens that investors may encounter.

Content access (Pillar 9) and domestic data laws (Pillar 7) are important aspects of domestic digital governance regulations. The heterogeneity and moderately high scores indicate restrictions in this domain, with common instances of limitations on commercial content, internet intermediaries liability regimes and instances of internet shutdowns . Together with the high RDTII score and similar heterogeneity observed in Pillar 8, the findings indicate that the fragmented and inconsistent harmonised frameworks for data protection, liability and content regulation across the continent impede digital transformation. The aforementioned Digital Trade Protocol (DTP) under the AfCFTA and the Digital Transformation Strategy (DTS) offer continental agreements and commitments by member states, which includes aspects such as data protection and cybersecurity efforts. These initiatives showcase the importance of data governance to support the digital growth on the continent.

3.4.1. Trade Facilitating performance UN Global Survey on Digital and Sustainable Trade Facilitation

The Digital Trade Regulatory Environment offers a comprehensive macro-level readiness of the environment for digital trade. Complementing this, the UN Global Survey on Digital and Sustainable Trade Facilitation provides insights into the operational implementation of digital trade measures, offering a new perspective to build upon the **potential** from the RDTII 2.0 framework towards **implementation**. Specifically, it ranks the countries' legal framework in four groups and twelve sub-groups across 62 trade facilitation measures which are based upon 1) data submission by experts, 2) data verification by regional commissions and 3) data validation by national governments (see Annex IV - UN Global Survey on Digital and Sustainable Trade Facilitation for a detailed overview of the trade facilitation measures):

1. **General Trade Facilitation**
    a. Transparency (5 measures)
    b. Formalities (8 measures)
    c. Institutional Arrangement and Cooperation (5 measures)
    d. Transit facilitation (4 measures)
2. **Digital Trade Facilitation**
    a. Paperless Trade (10 measures)
    b. Cross-Border Paperless Trade (6 measures)
3. **Sustainable Trade Facilitation**
    a. Trade Facilitation for SMEs (5 measures)
    b. Agricultural Trade Facilitation (4 measures)

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c. Women in Trade Facilitation (3 measures)

4. **Other Trade Facilitation**
   a. Trade facilitation for e-commerce (5 measures)
   b. Green trade facilitation (4 measures)
   c. Trade finance for trade facilitation (3 measures)

Sub-Saharan Africa has made continuous improvements in trade facilitation but still performs below the global average. In 2025, the region recorded an average of 62% across 31 digital trade facilitation measures, falling short of the global average of 71%. However, LDCs (Least developed countries) and LLDCs (Landlocked Developing Countries) have made significant progress between 2023 and 2025 on international trade, with good progress on paperless trade implementation, but poor/early-stage results on sustainable trade facilitation measures (green trade and e-commerce frameworks). Nevertheless, high trade cost and uneven regional development on digital trade facilitation (paperless and cross-border paperless trade) highlight how targeted support is needed for the AU to significantly improve its regional and global trade participation, emphasising the role of the AfCFTA to leverage harmonisation and digital interoperability among its member states [68], [69].

Table 2: Trade environment comparisons - country-specific among 5 regions.

Region	Country
North Africa	Egypt; Mauritania
Southern Africa	South Africa; Angola
West Africa	Nigeria; Ghana
Central Africa	Cameroon; Central African Republic
East Africa	Ethiopia; Madagascar

The following section illustrates the differences in trade restrictiveness among the continent (see Table 2). Two countries per region will be examined, a relatively strong performer and one weaker performer, based on their UN-ESCAP RDTII trade – and UNTFS performance offset by national digital trade policies. The analysis focuses on two categories of General Trade Facilitation, two categories of Digital Trade Facilitation and one on Sustainable Trade Facilitation.

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Trade Facilitating Performance North Africa

Egypt



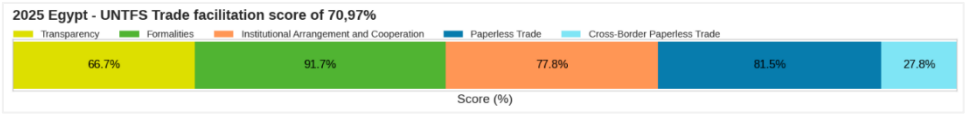


Figure 24: Egypt - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Egypt contains a moderate to high restrictive trade environment in Northern Africa in terms of trade facilitation (see Figure 24) [70]. With an RDTII value of 0.62, the environment demonstrates significant barriers among all 12 pillars, restricting digital trade integration. In particular, barriers to digital trade integration (score > 0.5[14]) are observed across all pillars except for tariffs and trade defence (Pillar 1) and public procurement (Pillar 2).

The UNTFS survey indicate well-established implementations of formalities and paperless trade with 91.7 and 81.5% respectively. **Institutional Agreement and Cooperation** follow next (77,8%), reflecting strong coordination with trade-related agencies. Cross-border paperless trade remains an area for improvement, with practical implementation progress of 27.8%. Egypt has a beneficial, but strict environment to facilitate digital trade, with strong points in its regulatory framework and practical implementations in **Formalities** and **Paperless Trade**. However, the country's area for improvement indicate that **Transparency** and **Institutional Arrangement** require further strengthening to enhance digital paperless trade and ensure efficient enforcement of regulations. **Agricultural Trade Facilitation** is well implemented, with full implementation of three out of the four measures, and partial implementation of an e-application for SPS certificates.

Recommendations

Following UNTF's recommendations, Egypt would further strengthen its digital and paperless trade environment by considering **1)** enforcing intellectual property violations through penalties and sanctions, **2)** reducing the patent backlog and **3)** offer transparent guidelines and procedures to patent applications. Additionally, **4)** reducing discretionary licensing by Egypt's National Telecommunications Authority (NTRA) to promote competition and access to telecommunication equipment and encryption, **5)** modernising and updating the regulatory framework on electronic transactions, e-contracts and e-signatures to reduce uncertainty and enhance businesses trust, and concluding with **6)** investigating and assessing the digital trade cost on data governance for Personal Data Protection [71].

NAFEZA is Egypt's National Single Window for Foreign Trade Facilitation, drawing similarities to EU's Single Administrative Document (SAD). NAFEZA offers importers and exports an online e-portal to automate custom administration that simplify procedures and reduce clearance times, bringing Egypt's trade system in-line with international trade-related standards procedures and custom requirements.

[14] An RDTII score above 0.5 indicates significant regulatory restrictions, suggesting barriers (e.g., regulatory restrictions on cross-border data flows) that hinder effective integration of digital trade.

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Mauritania





Figure 25: Mauritania - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Mauritania digital trade regulatory environment has the least regulatory restrictions in Northern Africa, with an RDTII score of 0.25 (see Figure 25) [72]. The country has made significant commitment to digitalisation and its progress indicates an early-stage development, with the foundational legal framework in place that includes telecommunications, electronic transactions, personal data protection and intellectual property and copyright [72]. However, the country only scores on eight out of the 12 RDTII pillars, highlighting regulatory gaps that limits its digital trade readiness. Additional, tariffs and trade defence (Pillar 1) and internet intermediary liability (Pillar 8) are scoring high (> 0.5) on the RDTII scale, signalling barriers for digital trade integration.

The UNTFS survey indicate strong performance on **Paperless Trade** with 77.8%, followed by average performance on **Institutional Arrangement & Cooperation**, and **Formalities** with 55.6% and 54.2% respectively. **Transparency** of its regulations and tariffs remain low with 40% measurement implementations and has seen no advancement since 2021. (Digital) trade facilitation for SMEs, agriculture and promoting women in trade remains not implemented. **Cross-Border Paperless Trade** has seen partial implementation of a legal framework and an electronic exchange of customs & SPS certificates. The trade facilitation score of 54.84% showcases implementations of key digital foundations but is still behind a fully integrated digital trade systems, particularly in transparency, formalities and interoperable processes. **Agricultural Trade Facilitation** remains underdeveloped; as of 2025, no measures related to SPS certificates and special treatments for perishable goods have been implemented.

Mauritania has seen improvements in trade facilitation and digitalisation with strong commitments in the digitalisation of its economy since 2019. However, advancement in this region has remain primarily stagnant since 2021.

Recommendations

Following UNTFS recommendations, Mauritania could consider **1)** signing conventions, such as the WTO Information Technology Agreement, to align further with global standards benefiting legality, lowering trade barriers and strengthen cross-border interoperability, **2)** clarifying handling and enforcing of e-commerce disputes and concluding with **3)** targeting and shutting down harmful sites rather than implementing national internet shutdowns which hampers the running of e-commerce [73].

ASYCUDA (Automated System for Customs Data) is a customs management systems developed by UNCTAD (UN Trade and Development) that offers the ability to handle manifests and customs declaration, automating and modernising customs procedures. Mauritania uses ASYCUDE World, a step-up version that offers alongside the previous features, implementation of cross-border paperless trade and electronic exchange of customs data [74].

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Trade Facilitating Performance Southern Africa

South Africa

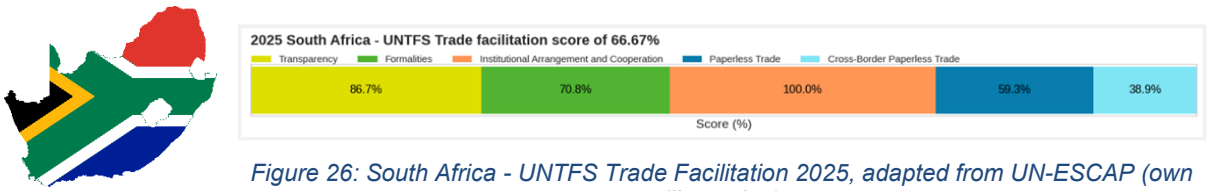


Figure 26: South Africa - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

South Africa's digital trade regulatory environment scores 11 out of the 12 pillars, indicating a regulatory state that does cover almost all key elements. However, the country scores indicate less regulatory restrictions with an RDTII score of 0.30, showcasing that the framework is in place, but the practical implementation and enforcement require further improvements (see Figure 26) [75]. South Africa scores high (> 0.5) among foreign direct investment (Pillar 3), telecom regulations and competition (Pillar 5) and internet intermediary liability (Pillar 8).

Data from the NTFS survey data prior to 2025 are not available for South Africa, but the 2025 numbers indicate strong performance, with a general trade facilitation score of 66.67%. **Institutional Arrangement and Cooperation**, followed by its transparency have all main measures either partially implemented or fully implemented. **Formalities** and **Paperless Trade** also show solid performance, with two measurements, 'expedited shipments and e-application certificates of origin' for formalities and paperless trade respectively, not yet implemented. **Cross-border Paperless Trade** is a work-in-progress with partial implementations of a legal framework and an electronic exchange of customs declaration, reflected by its score of 38.9%. However, interoperability and the legal framework require further development to establish a fully operational cross-border paperless trade system in South Africa. **Agricultural Trade Facilitation** signals mixed performance, with limited to no information on (electronic) SPS standards and special treatments of perishable goods. However, South Africa does have SPS testing and laboratory facilities fully implemented.

South Africa has a strong foundation of a digital trade environment, both in its legal framework (e.g., the Copyright Act of 1975 & Electronic Communications Act of 2005) and practical implementation through systems such as the South African Revenue Service (SARS) Registration, Licensing and Accreditation (RLA), allowing management of electronic customs RLA.

Recommendations

Following UNTFS recommendations, South Africa can further improve its digital trade environment by **1)** signing and ratifying treaties and agreements on (cross-border) interoperability, **2)** continuous investment in digital infrastructure, **3)** liberalise the telecommunication sector in line with the AfCFTA agreement, **4)** improve transparency on its regulation and tax thresholds and concluding with **5)** updating its e-commerce regulation [76].

SARS is the nation's tax collection authority, offering various tools to support digital trade facilitation, including its eFiling (electronic document submission) and RLA systems (enabling businesses to manage customs RLA). These systems are part of a broader incentive of South Africa to improve and adopt digitalisation practices that promote automation, transparency and efficiency across its customs and trade environment.

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Angola





Figure 27: Angola - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Angola contains a more restrictive regulatory trade environment compared to other countries in Southern Africa. Scoring 0.39 and a UNTFS trade facilitation score of 58.06%, Angola has made progress on the beginnings of a legal framework that supports digital trade (see Figure 27). Angola scores high (> 0.5) on tariffs and trade defence (Pillar 1), intellectual property rights (Pillar 4), telecom regulations and competitions (Pillar 5) and internet intermediary liability (Pillar 8), signalling areas of improvement to enhance its digital trade integration performance.

Similar to South Africa, NTFS data availability for Angola started in 2025, showcasing a general trade facilitation score of 58.06% (see Figure 27) [77]. The **Transparency** and **Formalities** measures indicate good progress on implementation, either partial or fully, across the previously mentioned 2 pillars. Angola scores well on **Institutional Arrangement and Cooperation**, with full implementation across the UNTFS measures. **Paperless Trade** showcases strong performance, with a fully automated customs system and partial implementation across all e-submissions and e-applications. **Cross-Border Trade** is an area of importance for Angola, with as of 2025 no regulatory frameworks and electronic exchanges of customs-related integration to enable cross-border trade. **Agricultural Trade Facilitation** consists of full implementations of SPS laboratories and testing, and special treatment of perishable goods. Limited to no information exists on SPS national standards and e-application of SPS certificates.

Recommendations

Angola has made good progress in establishing a legal framework supporting digital trade. Nevertheless, there are several gaps and challenges Angola should consider advancing its digital trade performance. Following UNTFS recommendations, Angola should **1)** continue to prioritise alignment with international trade standards and global norms, **2)** improve digital data governance on trade secrets (e.g., safeguarding business information, intellectual property rights) and **3)** reduce tariffs and trade defence measures [78].

Similar to Mauritania, Angola uses ASYCUDE World. ***ASYCUDA*** (Automated System for Customs Data) is a customs management systems developed by UNCTAD (UN Trade and Development) that offers the ability to handle manifests and customs declaration, automating and modernising customs procedures. ASYCUDE World is a step-up version that offers alongside the previous features, implementation of cross-border paperless trade and electronic exchange of customs data.

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Trade Facilitating Performance West Africa

Ghana



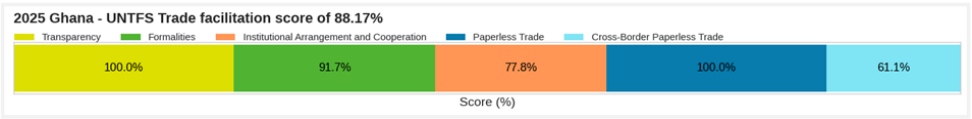


Figure 28: Ghana - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Ghana is a strong performer in digital trade in West Africa, containing a relatively open digital trade environment with an RDTII score of 0.26. The country scores high (> 0.5) among three pillars, particularly tariffs and trade defence (Pillar 1), domestic data governance (Pillar 7) and internet intermediary liability (Pillar 8), illustrating important areas to improve its digital trade integration.

The UNTFS score of 88.17% indicates strong performance across all the UN digital trade dimensions, ranking the highest among the 10 countries assessed here (see Figure 28) [79]. **Transparency** and **Paperless Trade** measures are fully implemented, indicating a mature digital trade facilitation environment. **Formalities** showcases a similar performance, with only expedited shipments and trade facilitation measures for authorized operators being partially implemented. **Institutional Arrangement and Cooperation** show partial implementations of a national regulatory framework for border agency cooperation and delegation of certain border controls to customs. Finally, **Cross-Border Paperless Trade** has demonstrated steady improvements in recent years, with a fully implemented regulatory binding framework for electronic transactions and partial implementations of digital authentications, electronic exchange of CoO and SPS certificates, and paperless collection of payments from letter of credits. **Agricultural Trade Facilitation** is well established in Ghana, with full implementation among three of the four measures, and partial implementation of the e-application of SPS certificates.

Ghana has a well-established, open and enabling digital trade environment, supported by its legal framework for electronic transactions, intermediary liabilities and alignments with international standards for online payments overseen by the Bank of Ghana – particularly the Payment Card Industry Data Security Standards (PCI DSS), ISO 8583 (financial transaction messages) and Europay, Mastercard and Visa (EMV).

Recommendations

Following UNTFS recommendations, Ghana should **1)** strengthen the role of internet intermediaries in online payments to guard against fraud, **2)** increase participation in international conventions on electronic communications and transactions to support cross-border digital trade, and **3)** regulate unwanted advertising [80].

The ***Integrated Customs Management System*** functions as Ghana's e-customs management system. Introduced in June 2020, the system was created to improve coordination across cross-border trade activities, improve efficiency and transparency (e.g., revenue mobilisation) within the customs trade environment.

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Nigeria

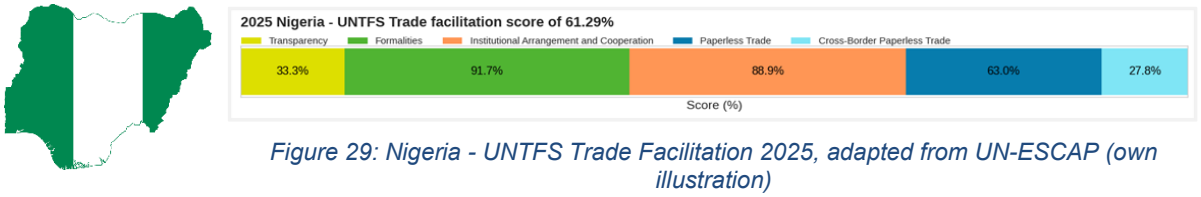


Figure 29: Nigeria - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Nigeria contains comparatively a restrictive trade environment, with an RDTII score of 0.45 and scoring high (> 0.5) among seven pillars, indicating barriers to digital trade integration.

The UNTFS trade facilitation score of 61.29% highlights strong performance in **Formalities** and **Institutional Arrangement and Cooperation,** showcasing significant improvements in this domain since 2015 (see Figure 29) [81]. **Paperless Trade** performance indicates good progress, with most measures either partially or fully implemented. However, gaps remain in the implementation of electronic application for preferential Certificates of Origin (CoO) and electronic custom refunds. Implementation gaps exist in **Cross-Border Paperless Trade**; however, progress has been made through partial implementations of regulatory frameworks for electronic transaction and the paperless collection of payment from letter of credit. Performance in **Transparency** remains weak, with limited implementations observed. While partial implementations of stakeholder consultation and appeal mechanisms are in place, advance notification of trade regulations remain in a planning stage. Discriminatory treatment between domestic and foreign digital service providers and limited transparency in its internet governance impede cross-border data flows and limit deeper digital trade integration. From a sovereignty perspective, local capacity building and national protection objectives are valid reasons but discourage trade and foreign investments. Nigeria has signed several trade-related agreements such as the WTO agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), boosting confidence among foreign entities. However, lack of transparency in its fair use and rules may discourage cross-border digital trade investments. **Agricultural Trade Facilitation** shows strong performance, with full implementation of SPS standards and special treatments of perishable goods. SPS testing and laboratories remain in a planning stage.

Recommendations

Following UNTFS recommendations, Nigeria should **1)** increase transparency in its policy decisions and regulatory decision-making, **2)** harmonising domestic standards frameworks (e.g., Nigerian Industrial Standards) with international-recognised standards and frameworks and **3)** ensure that regulatory measurements are calibrated, non-discriminatory and minimally invasive [82].

B'Odogwu is Nigeria's customs management system, developed to streamline customs declarations, automate compliance and improve data governance. The system has been fully operational since November 2024 and early evidence indicates good performance, particularly on its real-time data, automated risk assessment and inter-agency collaboration.

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Trade Facilitating Performance Central Africa

Cameroon



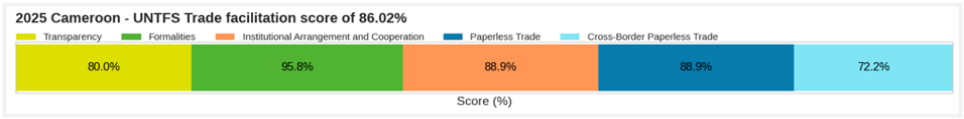


Figure 30: Cameroon - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Cameroon has a moderate restrictive trade environment with an RDTII score of 0.39, scoring high (> 0.5) among three pillars: tariffs and trade defence (Pillar 1), internet intermediary liability (Pillar 8) and standards and procedures (Pillar 11).

The UNTFS score of 86.02% indicates strong performance among all UN digital trade dimensions, similar to the performance of Ghana (see Figure 30) [83]. **Transparency** has seen significant progress since 2023, with full implementations on online publications of import-export regulations and stakeholder consultation on draft regulations. Partial implementations remain for notifications of trade regulation; advance rulings on import tariffs, and an independent appeal mechanism. The **Formalities** are well-established, with full implementations across all UN digital trade dimension, except for expedited shipments, which remain implemented partially. **Institutional Arrangement and Cooperation** are also well developed, with full implementations in regulatory frameworks for trade facilitations and border agency cooperation, and partial implementation in delegating border controls to customs and alignment of formalities with neighbouring economies. **Paperless Trade** is well-established, with full implementation among all major e-submission and e-commerce implementations, with currently partial implementation in e-application of CoO, e-payment customs duties and an e-application for customs refunds. **Cross-Border Paperless Trade** shows (partial) implementation among five of the six dimensions, with the creation of a legal framework for digital authentication currently in a planning stage. **Agricultural Trade Facilitation** indicates good performance, with full implementations on SPS standards, special treatment of perishable goods and partial implementation of SPS testing facilities. E-application of SPS certificates remain in a planning phase.

Recommendations

Following UNTFS recommendations, Cameroon should **1)** amend regulation on electronic commerce that is currently restricting cross-border digital trade (Act No. 2010/021), **2)** enforce a data governance and protection framework, **3)** liberalising e-payment regulations and **4)** improve alignment with DTP on digital trade protocols (DTP) and international standards [84].

Camcis (Cameroon Customs Information System) is the nation's E-customs platform, integrating the entire customs clearance procedure to shorten import and export procedures while improving customs duties and taxes. Superseding Sydonia++, Camcis offers extended functionality, including automated risk assessment, paperless submission of trade documentation, and integration between other governmental agencies such as Cameroon's Single Window (GUCE).

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Central African Republic

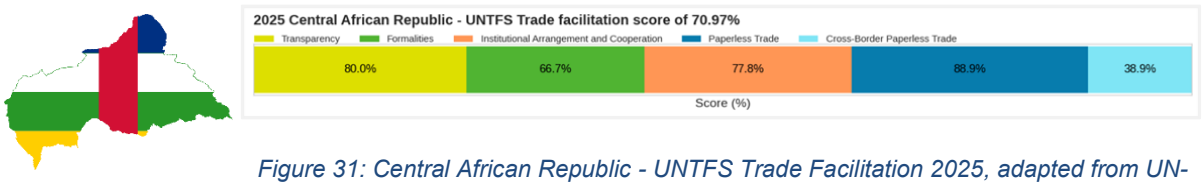


Figure 31: Central African Republic - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Central African Republic has a relatively open trade environment with frameworks in-place for all 12 pillars, scoring 0.34 on the RDTII scale. The country scores high (> 0.5) on tariffs and trade defence (Pillar 1) and internet intermediary liability (Pillar 8), signalling barriers that restricts digital trade integration.

The UNTFS score of 70.97% signals good integration among the five dimensions, with Transparency and Formalities reflecting the start of a well-established framework (see Figure 31) [85]. **Formalities** show partial implementations among all eight measures, while **Transparency** is partially implemented in three out of the five measures, with full implementation on stakeholder consultation on draft regulations and advance notifications of trade regulations. **Institutional Arrangement and Cooperation** indicate similar findings, with partial implementations among three out of the five dimensions, with full implementation on a national committee on trade facilitations and alignment of formalities with neighbouring economies. Central African Republic scores particularly well on its **Paperless Trade** implementations, with full implementations among all seven of 10 dimensions, with partial implementations on its e-application of CoO, customs duties and custom refunds. **Cross-Border Paperless Trade** is less developed, but indicates strong commitments, with laws and regulations for e-transactions, electronic exchange of customs declaration and CoO currently in a planning stage. **Agricultural Trade Facilitation** is in an early phase, with (electronic) SPS standards and special treatments for perishable goods being partially implemented.

Recommendations

Central African Republic trade regulatory frameworks demonstrate a relatively open trade environment, allowing nationals and foreigners to invest and trade freely; however, gaps remain. Following UNTFS recommendations, Central African Republic should **1)** improve its data governance protection on personal data and electronic transactions (incl. consumer safety), **2)** establish safe harbours for internet intermediaries and **3)** improve alignment with international standards (e.g., intellectual property rights and payment security) [86].

eDouanes is the nation's e-customs portal, designed to modernise customs control and improve revenue security. The system offers digital tools for the full online submissions and processing of customs declarations. By automating key custom procedures, the system lays the foundation for modern, cross-border paperless trade.

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Trade Facilitating Performance East Africa

Ethiopia

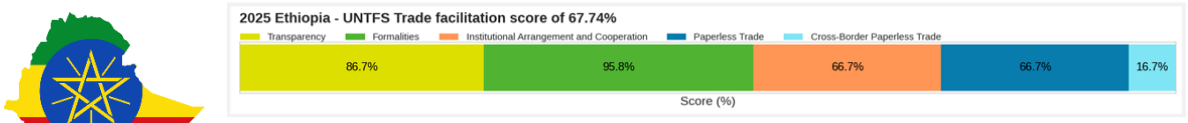


Figure 32: Ethiopia - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Ethiopia contains a moderate to highly restrictive digital trade environment, with an RDTII score of 0.47. Six out of the 12 pillars show elevated digital trade integration restrictions (> 0.5): tariffs and trade defence (Pillar 1), intellectual property right (Pillar 4), telecom regulations and competition (Pillar 5), domestic data protection (Pillar 7), standards and procedures (Pillar 11) and online sales and transactions (Pillar 12).

The UNTFS score of 67.74% indicates moderate implementation of digital trade facilitation measurements (see Figure 32) [87]. **Transparency** and **Formalities** are well-established, with full implementation of seven of the eight Formalities measures and three out of five Transparency measures, while the remaining implementations are partially implemented. **Institutional Arrangement and Cooperation** show a good foundation, with partial implementations of three out of five measures. Full implementation currently exists for the delegation of border control to customs, while the national committee on trade facilitation remains in a planning stage. **Paperless Trade** is well established, with full implementation of six out of 10 measures. The electronic application of CoO and custom refunds are not implemented, while the electronic Single Window System is currently in a planning stage. **Cross-Border Paperless Trade** remains underdeveloped, with five out of six measures not implemented, though the paperless collection of payment from letter of credit has been fully implemented. **Agricultural Trade Facilitation** is well established, with three of the four measures – including SPS and special treatment of perishable products - fully implemented. SPS testing and laboratory facilities remain partially implemented.

Recommendations

Ethiopia's digital economy shows promising progress, supported by current policy reforms, with digitalisation playing a key factor. Following UNTFS recommendations, Ethiopia should **1)** expand competition in the telecommunication market, **2)** improve data governance (incl. data protection, payment regulations and consumer protection), **3)** revise strict telecom and ICT equipment import rules, **4)** improve transparency on internet and social media interruptions to minimise disruption to digital trade, **5)** facilitate online registration (incl. businesses, tax, customs) and **6)** improve infrastructure and institutional capacity to enable and verify digital signatures [88].

Electronic Customs Management System (eCMS) is Ethiopia's national online customs portal, a fully automated clearance systems that enables traders to fully submit custom declarations online, receive feedback and track shipments electronically. Replacing ASYCUDE, eCMS provides a modern, interoperable platform that speeds up customs clearance while reducing the need for physical presence.

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Madagascar



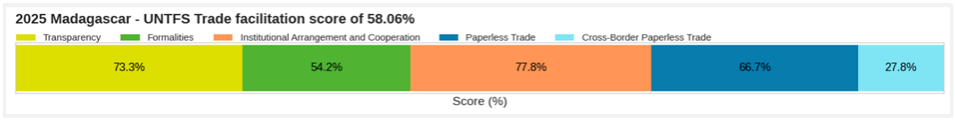


Figure 33: Madagascar - UNTFS Trade Facilitation 2025, adapted from UN-ESCAP (own illustration)

Madagascar has a relatively open digital trade environment with an RDTII score of 0.26. The country scores high (> 0.5) on two pillars: tariffs and trade defence (Pillar 1) and internet intermediary liability (Pillar 8).

The UNTFS score of 58.06%, similar to Angola, showcases moderate implementation of digital trade measures (see Figure 33) [89]. **Transparency** has three of five measures fully implemented, with partial implementation of online publication of import-export regulations while advance notifications of trade regulations remain unimplemented. **Formalities** show mixed results, with publication of average release times being the only fully implemented measure. Partial implementations exist for four measures, including risk management, pre-arrival processing, post-clearance audits and acceptance of copies for trade formalities. Trade facilitation measures for operators and expedited shipments are in a planning stage, while release from final customs duties determination remains unimplemented. **Institutional Arrangement and Cooperation** show good progress, with two partial implementation and one full implementation of the five measures. Alignment of working days and formalities with neighbouring countries remain unimplemented. **Paperless Trade** is well established, with full implementations of five of 10 measures, and partial implementations of three. No electronic application of CoO and customs refund currently exists. **Cross-Border Paperless Trade** is in its early-stages, with partial implementation of regulatory frameworks for electronic transactions and SPS certificates. An electronic exchange of CoO remains in a planning stage, with no implementation of a digital authentication framework and electronic exchange of customs declarations. Little to limited information exists on paperless collection of payment from letters of credit. **Agricultural Trade Facilitation** is in an early stage showcasing good progress, with partial implementation of SPS testing and electronic application of SPS, with full implementation of special treatments for perishable goods. SPS national standards have not been implemented.

Recommendations

Madagascar has a relatively open trade environment, supported by well-established legislation. However, several laws remain inapplicable to digital trade. Following UNTFS recommendations, Madagascar should **1)** adopt and implementing data governance legislation (e.g., personal data protection, electronic transactions and signatures), **2)** refine existing legislation to close loopholes, especially in internet traffic regulations and internet intermediary liabilities, **3)** improve security and effectiveness of e-commerce (e.g., technical and financial resources) and **4)** facilitate mechanisms to improve transparency, dispute and predictability for digital trade transactions [90].

GasyNet's TradeNet is Madagascar's automated customs platform, designed to automate and streamline customs procedures. It offers electronic submission of import and export declarations, automated risk assessment and integration with other governmental agencies.

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Key Findings from the Regional Analysis

The digital trade environment analysis of 10 African countries among five regions showcased progress, gaps as well as regional trends. Strong overall digital trade performance - according to the UNTFS Survey 2025 - was observed in Ghana and Cameroon, while other countries showed ongoing progress and commitments towards digitalisation in recent years. Steady progress was observed among all in Formalities, Institutional Arrangement and Paperless Trade. Cross-Border Paperless Trade, except for Ghana and Cameroon, appears to be an area of improvement, showing recent progress, but lagging behind the other trade dimensions. Agricultural Trade Facilitation follows a similar trend, with the exception of Mauritania, showcasing steady progress with established (electronic) SPS facilities and standards, and special handling of perishable goods. The RDTII results indicated relatively open trade environments in Mauritania, Ghana and Madagascar, with moderate restrictions observed in South Africa, Cameroon and the Central African Republic. A moderate to high digital trade environment was observed in Egypt, Angola, Nigeria and Ethiopia. Across all countries, and following similar observations for the African continent, gaps remain in tariffs and trade defence (Pillar 1), telecom regulations and competitions (Pillar 5), internet intermediary liabilities (Pillar 8), and standards and procedures (Pillar 11). Additionally, data governance frameworks, including intellectual property rights and consumer and business protection, remain underdeveloped and emerged as a recurring (policy) recommendation among all countries.

3.5. Conclusion

2.	Which regulatory frameworks currently support digital agricultural trade, and how do they support cross-border paperless trade?
3.	How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?

Chapter 3 assessed the state of digital infrastructure, role of digitalisation in trade facilitations and offered a detailed overview of Africa-EU trade requirements and regulatory trade performance in Africa. Connectivity across the continent has made great strides, with mobile internet connectivity uptake remaining a key driver of existing agricultural digital solutions and their benefits. However, there remains a high usage gap, with the continent falling behind other regions, indicating an important area of improvement. Data exchange among trade partners – consisting of master, transactional and visibility data – is a crucial aspect to fit with trade documentation compliance and supporting agricultural value chains. This has become an important topic for the AfCFTA DTP, DTS and CAADP, and other commitments under Agenda 2063, with the AfCFTA DTP building upon existing frameworks and guidelines that support cross-border paperless trade (e.g. electronic invoices, digital identification and data interoperability). However, the success of these commitments depends on multiple factors, with most notably the political will of the state parties to align national strategies, frameworks and capacity with the objectives of the DTP, DTS, CAADP and related AU-initiatives.

Recent years has seen significant progress in the creation of national digitalisation strategies, custom digital trade systems, and regulatory developments, despite the apparent regional differences in Africa's digital trade environment. North Africa tends to contain a more restrictive digital trade environment with well-established rules, formalities and protective measures that limit market access and complicate cross-border digital trade. Southern, East and parts of

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West Africa[15] on the other hand exhibit relatively a more open and harmonised digital trade regulatory environments, however, this openness is often driven by regulatory gaps, particular in digital data governance, which undermines the regulatory trade coherence and overall implementation scores. While substantial regional differences exist even within regions, the overall trade environments in the AU tends to be more open than that of Asia-Pacific but remains more restrictive compared to the Latin America and the Caribbean (LAC) region.

Despite the commitments set by African member states, the current fragmented and uneven regulatory landscape hinder effective regulatory implementations, with the current trade digitalisation index score falling behind other global regions. Nevertheless, the success of these ambitions depends on the political will of member states to implement the frameworks and required capacity-building investments effectively.

[15] It should be noted that the RDTII framework measure the presence of regulatory restrictiveness/openness rather than full implementation. As a result, some lower-scoring countries may appear containing a more open environment for digital trade facilitation due to limited regulatory framework rather than digital trade readiness.

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4. Digital Solutions and Tools in Practice - Findings from Case Studies & Systematic Literature Review

Chapter 4 consists of the results from the systematic literature review (SLR) and the findings from the case studies (tea, cassava and GS1 Rwanda). The chapter starts with a descriptive overview from the academic papers, followed by the main findings from the SLR. A detailed description of the various digital tools/solutions in practice is given, drawing insights from the SLR, desk research and *CTA: The Digitalisation of African Agriculture Report* [1]. **Case Study 1** explores the role of digitalisation and food safety standards (Codex HACCP, with a particular focus on cyanide/lead contaminants) to enhance transparency, monitoring and complying with EU's food safety regulations, drawing insights from desk research and an empirical case study. **Case Study 2** explores the role of digital solutions and tools in the African tea sector to improve traceability and transparency, exploring the role of digital tools on quality metrics and investigate the role of Critical Control Points (CCPs) through desk research and an empirical case study. Lastly, **Case Study 3** provides insights into the implementation of GS1 Standards in Rwanda, exploring how interoperable standards, such as issuing national barcodes, supports the country's commitments to improve digital trade facilitation. It draws insights from a systematic literature review, desk research, Policy and Regulatory framework analysis, Trade and Digitalisation datasets, findings form case studies and a conducted survey. Chapter 4 answers the following research questions:

3.	How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?
4.	What types of digital agricultural solutions are currently being used across Africa and what do case studies reveal about success, challenges and opportunities of digital tools?

Chapter 4 demonstrated how digital standards, tools and systems play a key role in improving food safety standards, traceability and market access, shown through the academic literature and the cassava, tea and GS1 Rwanda case studies. While global standards (e.g., SPS, GS1 and HACCP) and digitalisation across African value chains offer great potential to improve transparency, food safety standards and compliance with international-recognised standards, underdeveloped and fragmented regulatory implementations continue to constraint trade and international competitiveness.

4.1. Overview of Digital Solutions and Tools

A systematic approach was performed to map current trends, knowledge and technologies. The review combined insights from academic sources (Scopus, Web of Science, ScienceDirect and IEEE Xplore) as well as several grey literature sources, including sources from AU, FAO, UN, World Development Bank, CTA and more. See Annex II - Methodological approach for a detailed overview of the methodology of the systematic literature review.

The systematic literature review consisted of analysing 54 academic papers, followed by 33 sources of grey literature[16]. The geographical scope of the studies indicates regional differences, with West and East Africa being more representative compared to North and Southern Africa. The Southern region is mostly represented by South Africa (see Figure 34).

[16] Literature published outside traditional books or scholar journals that is not peer reviewed.

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The Northern region with Mediterranean countries is not well represented in the academic sources, with Morocco being the focus in studies addressing the MENA region.

4.1.1. Descriptive overview Systematic Literature Review

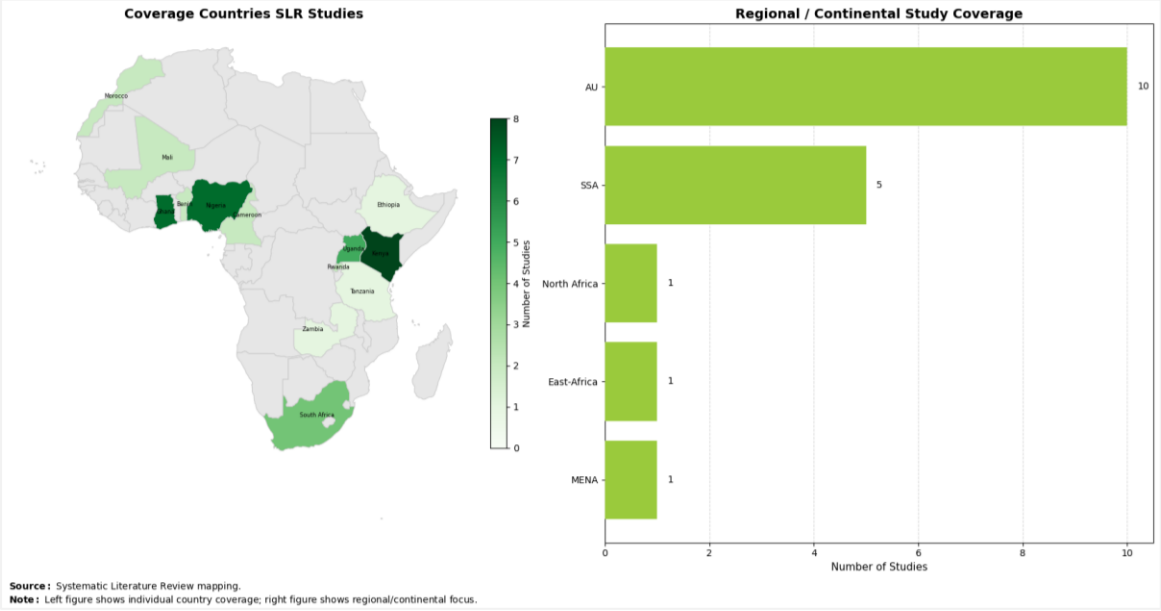


Figure 34: Overview Coverage SLR

Nevertheless, several meta studies included in the SLR consisted of a continent-wide approach, with 1 study focusing primarily on the MENA region. Sub-Saharan Africa is represented the most. Out of the 54 studies, 10 of the literature sources covered the entire continent.

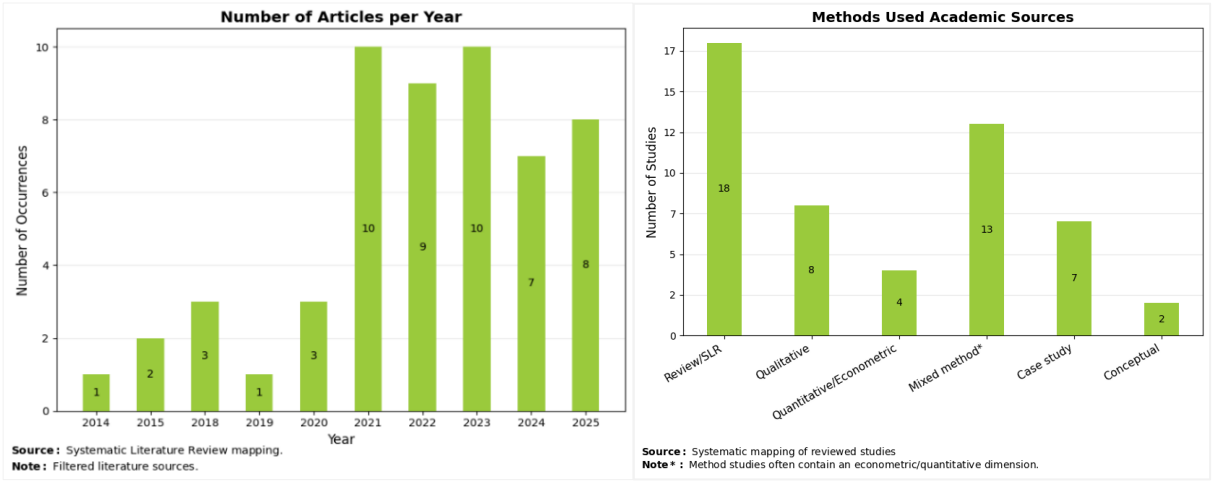


Figure 35: Overview Publication Year & Methods used

The timeframe of the sources is very recent, with most of the filtered sources published after 2020 (see Figure 35). Recent interest in digitalisation of the food systems in Africa can be linked to the COVID-19 pandemic that forced countries to accelerate and investigate automatic (digital) solutions, especially in trade systems. Grey sources and reports, contemplated by the relative recent trade agreements and commitments on digitalisation in the African Union, also indicate a similar trend, with many of the sources published just before or during the COVID-19 pandemic.

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From a methodological standpoint, reviews and a mixed-method approach are the most common methods, followed by case studies and qualitative research. The dairy sector, cocoa and banana food systems were explored the most in the papers, followed by maize, soybeans and potatoes. Despite an explicit search towards standardisation techniques and trade-related digitalisation in African agri-food chains, a knowledge gap in the academic literature can be clearly determined regarding these topics, hence the big emphasis on grey literature sources. This gap will be addressed in a future academic paper by the authors.

Taking a closer look at the scope and focus of the actors in the agricultural supply chain from the SLR, 6 main clusters can be identified[17]:

- **Producers**, consisting of smallholder farmers, producers, farm owners and farming communities.
- **Market Actors**, such as processors, manufacturers, (intermediary) traders, buyers, SMEs and retailers.
- **Institutional Actors**, of which governmental institutions involved in agricultural, food- and market-related domains.
- **Financial Actors**, with financial institutions such as banks, micro-financing and investment companies.
- **Tech and Start-Up Actors**, consisting of companies providing digital extension services, solutions and other digital services such as fintech to farmers and agricultural actors.
- **Research and Academia Actors**, such as universities and research institutes.

Primarily, each paper discusses the African agricultural value chain, with the farmer and specifically the smallholder farmer being the focus point in about 70% of the papers (n = 37). Institutional actors follow next, being part of the focus group in about 50% of the papers (n = 26). Following institutional actors, Tech and Start-Up is represented in about 34% (n = 18) of the papers. Market actors are included in about 26% of the papers (n = 14). Research and Academia (24,5%), Financial actors (17%) follow next. Other actors (broad scope, NGOs, communities, trainers) are represented in 26% of the papers (n = 14).

4.1.2. Systematic Literature Findings

This section describes the empirical findings from the included studies, focusing across four main thematic areas: (1) **Main Landscape and Developments** showcasing current trends in digitalisation practices), (2) **Barriers & Challenges** towards digital adoption, (3) **Key Adoption Drivers Digital Agri-Food Systems** and (4) **Key Digital Agricultural Technologies Available**.

1. Main Landscape and Developments

1. Growth in digitalisation and renewed interest

Availability of digital tools and services for African farmers has seen a steady increase on the African continent during the COVID-19 pandemic that forced countries globally to come up with new solutions in the agricultural value chain to combat the pandemic [91], [92]. Renewed interest in the digitalisation of African agriculture is also reflected in the increased interest in

[17] Multiple actors can be part of the focus group of the paper.

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academic literature and funding of projects since the start of 2020, primarily from foreign sources and institutes in the USA, Europe and Asia [28]].

2. Policy ambitions and continental strategies

The continent's ambition under Agenda 2063, AfCFTA and CAADP indicate the fundamental shift of transforming the continent through its agricultural backbone, with digitalisation of the sector as a key driver strategy [58], [93], [94]. To achieve inclusive growth and development, eliminating hunger and unity the continent through harmonisation, agricultural development plays a key role in the continent's aspiration. The AfCFTA and the recently renewed CAADP Kampala agreement highlight the importance of standardisation and digitalisation in the AVC to build towards better integration on trade-related practices (certificates, custom documentations, traceability) [19], [95]. The continent aims to incorporate more value-addition practices in the AVC, boosts intra-African trade to become less dependent on foreign food imports with the increasing population and build resilient value chains against climate change.

3. Uneven geographical adoption and project sustainability issues

Despite strong incentive to integrate and provide digital solutions to AVC actors, digitalisation is most prevalent and concentrated in a select number of countries in the South, West and North of Africa [48]. Fewer reports and insights can be obtained from the Sahel and Central African region as well as the Horn of Africa [48]. Smaller African countries in the MENA region have little to no documented knowledge on digitalisation in agriculture, with conflict areas being more practically oriented with their digital solutions [48], [91]. Uneven geographical adoption across Africa is a reoccurring trend, with digital divide within the countries and communities being cited as an important challenge on enhancing the sector through digitalisation [48], [91], [96], [97], [98], [99].

Alongside the uneven geographical distribution, existing African projects focusing on digitalisation themes for the AVC fail to mature into sustainable systems. A large part of the donor-driven pilots are short-term projects that do not generate structural change after the end of the project's timeline [96], [100].

4. Trade dynamics in Africa

From a trade perspective, Mkansi et al. explored how agricultural SMEs perceived export market access in Southern Africa, concluding that there is a strong desire to enter export markets due to better prices and support, but both internal (finance, know-how) and external barriers (lack of support, infrastructure & underdevelopment value chains) poses barriers to entry [97]. These barriers are a recurring theme and showcases why intra-African trade is only a small part of all African agriculture's trade [96], [97]. The fragmented trade landscape among African countries, consisting of complex required standards, licenses, documentations and trade barriers, hinder the continent's ability to boost intra-African trade [101], [102], [103], [104], [105], [106]. The AfCFTA Digital Trade Protocol aims to address the fragmentation through offering a framework on standard practices across 11 key topics, offering party members frameworks to incorporate in their domestic agricultural transformation strategies [26], [107]. Nevertheless, party members' political commitment and capacity buildings are significant drivers for its success to boost trade growth, regional integration with members and unification across the continent's commitments.

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5. EU-African trade regulations

EU regulation and existing certification and market standards directly affect African exporters. The EU's increasing sustainability and certification requirements through for example EU's EUDR, and the Green Deal SPS/IPM certification, brings new demands on agricultural processes. On top of these upcoming regulations, the existing SPS certification require (digital) upkeeping in various agricultural processes that benefit from digital implementations.

Certification standards show mixed, but important impacts for African farmers. A study by Sadeu et al. on cocoa certification schemes concluded that certified farmers (GAP, UTZ, Fair Trade, Rainforest Alliance) gained higher income through better yields versus non-certified farmers [108]. Certified firms also had improved access to EU markets, offered better contractual agreements and working conditions compared to uncertified farms according to a paper by Akrong et al. on the GlobalG.A.P.[18] certification on mango farms in Ghana [103].

At the same time, certification does not lift farmers out of poverty and the premium it offers plays only a small role compared to socio-contextual factors [103], [108]. A wage inequality between men and women still exists, regardless of the degree or equality in tasks [103]. Finally, the required training of workers is often a spillover effect through the participation of the (farm) owners in specific farmer-based organisations (FBOs), rather than the certification standards [103].

6. Digitalisation developments and farmer-level impacts

The current developments in the digital sector throughout Africa, with increased coverage, internet accessibility and mobile phone adoption, has brought the emergence of new tools and solutions [1], [2], [28], [45], [48]. Choruma et al. highlights how many of these new innovative solutions (extension services, fintech and more) were made possible by investments from domestic telecommunications companies and technology companies [28], [48]. More recently, Njuguna et al. observed a shift from generic digital tools – low-cost information exchange – towards more farm-specific and data-driven solutions. These newer tools offer tailored advice to farmers through the use of diagnostics and sensor-generated data [49].

Evidence from literature regarding benefits directly linked to digital tools for smallholder farmers include:

1. Improved market access, (farming) knowledge and lower transaction costs outside local markets,
2. Improvements in record keeping, transparency and access to large buyers,
3. Higher profitability.

Despite the emergence of new digital solutions, many smallholder farmers face barriers, ranging from limited knowledge, credit and market access to high internet cost and poor network coverage [28].

In conclusion, these trends showcase the rapid but uneven developments in the current digital landscape in Africa. The following section provides a deep dive of the digital services and tools

[18] GLOBALG.A.P. is a brand of smart farm solutions established in 1997 by FoodPLUS GmbH in Cologne, Germany in collaboration with stakeholders across the food industry. These solutions include standards for safe, socially and environmentally responsible farming practices.

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currently available to farmers, followed by a continent-wide visual overview of existing companies and services available.

2. Barriers & Challenges

1. Digital Literacy & Human Capacity Constraints

Limited digital and technical capacity of farmers and value chain actors hinder the adoption of digital agricultural technologies [28], [92], [109], [110], [111]. Access to these digital tools is often unevenly distributed across the continent and within regions, resulting in digital literacy, especially among older farmers who are often unfamiliar with digital agri-food solutions [28], [96], [98], [109]. In addition, many digital tools were conceived as not user-friendly; interfaces are often poorly translated and overly complex, making it difficult to control. When combined with the cost associated, these factors reduce the perceived usefulness and limit adoption [28], [91], [104], [112].

2. Infrastructure

Digital solutions generally require (access to) electricity and connectivity (internet, mobile network) to operate properly. Mobile network coverage and mobile phone adoption in the AU has greatly improved in recent years, offering opportunities to channel digital services to farmers [45], [50]. However, (mobile) network speed and reliability, high internet cost, limited access to electricity in rural areas and high investment cost of capable hardware hinder the adoption of digital solutions by farmers [28], [49], [100], [113]. These infrastructure constraints hinder real-time exchange of digital markets participation, digital financial services and information, mitigating the benefits of digital solutions for agriculture to farmers [28], [100], [112]. Finally, global developments, especially the increasing demand and shifting focus towards datacentres and AI, impact the availability of (consumer) hardware, such as RAM and NAND memory, which is essential in any technological device. This creating external barriers that require smart strategies to optimise hardware use and develop locally adapted solutions for digital adoption.

3. Economic Feasibility

The emergence of digitalisation in the AU has created new opportunities for start-ups and entrepreneurs to provide solutions to actors in the agri-food chain. However, the long-term economic effect of their business models is often unknown, leading to failed attempts and uncertainty for the end-users regarding the value proposition of digital services [1], [28], [100], [112], [114]. One of the reasons is the low incentive to pay for an agriculture service by farmers, complicating the ability to achieve critical mass for profitability [96], [112]. Scaling of these new business models is also uncertain, with many solutions still operating in an early phase (pilot, start-up or research driven/donor funded) that are not (yet) transitioning into commercially viable business models [1], [49], [91], [97]. Uptake of advanced solutions (drones, smart devices, software) require high upfront cost by the farmer, with ongoing expenses on maintenance, training and connectivity costs. This high cost can lead to knowledge disparities and inequalities between farmers who are able to afford these solutions and those who are not [28], [91], [100]. Simple technical solutions are therefore more likely to reach mass adoption [28]. In general, digital solutions for agriculture are advancing too quickly, outpacing the readiness of entrepreneurs, users and government actors to embrace and leverage them properly [1].

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4. Social & Institutional Inequalities

Social and institutional inequalities limit equal adoption and shared benefits from digital agri-food solutions, resulting in barriers such as digital divides, reinforcing (market) power inequalities, exclusion of adoption and gender inequality, especially among women [28], [91], [100], [102]. Institutional structures often shape these inequalities by following the interests of corporate and more powerful actors, while limiting participation and representation of smallholder farmers and workers [102], [104]. Similar patterns have been observed in certification and standards, which despite the social and sustainability objectives, insufficiently addressing workers representation and socio-contextual factors [103], [108], [115]

5. Technology Design

The design of digital interfaces, apps and programs in digital agri-food solutions often insufficiently reflects the needs and experiences of smallholder farmers, particularly older users with limited experience of digital hardware [28], [49], [91]. Difficulty in navigating complex menus, lack of local language options and a dependence on text-heavy interfaces create significant barriers for novice users, especially those with low literacy and digital literacy skills [1], [28]. These design limitations are further exaggerated by socio-contextual factors such as inconsistent mobile connectivity and limited access to reliable devices [98], [116]. A Human-Centred Design approach that addresses the local socio-contextual factors of smallholder farmers, including limited digital skills and infrastructure constraints, should be taken to improve the useability and effectiveness of digital agri-food solutions for smallholder farmers [28], [109].

3. Key Adoption drivers of Digital Agri-Food Solutions

1. User-Centred Development Programs

To address digital literacy & human capacity constraints, academic findings indicate a need for targeted bottom-up training and knowledge sharing programs that fit the local cultural context and language [1], [28], [96]. Such initiatives focus on building skills, awareness and confidence among (smallholder) farmers, while also helping to incentivise and attract the next generation of farmers that is more accustomed to digital tools [28], [92], [100], [114]. Literature findigs suggests that the previously mentioned barriers hindering effective adoption of digital agri-food solutions often isn't because of a lack of available tools that farmers could utilise to improve agricultural practices and benefits, but rather to the rapid pace of digital developments, outpacing the readiness of users, entrepreneurs and governmental agencies [1], [48], [96]. Education and awareness initiatives should recognise and address users' unfamiliarity and discomfort with digital tools, showcasing the practical benefits and mitigating digital literacy in the process while improving resilience to climate shocks [28], [96], [100], [109].

2. Infrastructure

Digital agri-food solutions require reliable infrastructure to provide connectivity and electricity to function properly. Despite the impressive uptake of mobile phone adoption and connectivity among the continent in recent years, limited access to electricity and affordable connectivity hinder broader adoption, as shown by the high usage gap in Figure 18 [28], [45], [50], [96], [100].

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Telecommunication companies have been a large contributor to digital adoption, providing internet services and mobile networks, including to farmers in rural areas [96], [117]. However, limited and slow internet access, combined with high costs poses barriers for farmers to fully leverage digital tools, restricting their ability to access real-time information necessary for decision making and market participation [28], [113], [117].

Continuous investment in electricity infrastructure (power stations/transformers, power lines and transmission networks/substations) and internet connectivity (subsea cables, fibre, datacentres, mobile networks and servers), is needed to keep up with the digitalisation commitments by the AU [1], [28], [48], [100]. Without opportunities to charge devices or connect to the internet, phones and subsequently software application will not work. At the same time, grid extension across the continent is unlikely to happen soon, emphasising the importance of solar-powered solutions and batteries to provide electricity to homes, farms and businesses [49], [96].

To align with the local rural context and the limited availability of mobile network coverage, offline- or low-data functionality should be incorporated in digital agri-food solutions [48], [96]. Alongside physical infrastructure, further investments into soft infrastructure (public services, regulatory frameworks and (intangible) systems to support physical network infrastructure) is also essential to ensure sustainable development of physical and soft infrastructure supporting digitalisation [1], [28], [96].

3. Business Models & Financial Incentives

A large share of digital agriculture solutions has emerged in recent years, with the CTA report noting that two thirds of the 390 identified distinct active solutions in 2019 were established during the 3 years of the CTA survey runtime [1], [96]. Many of these solutions operate through donor-funded projects or pilots and remain highly dependent on public funding [91], [96], [112]. Hence, these solutions often lack long-term sustainable business models, leading to uncertainty and market distorting at the scaling stage [28], [96].

Success stories of more mature existing solutions tap into the potential of providing public-private partnerships (PPP), such as *DigiFarm* and *iCow* in Kenya [48], [96]. These companies joined forces with local telecommunication companies, offering benefits to its users (digital extension service to farmers) while mobile network providers gain subscribers and increasing use of their platform. These examples illustrate the importance of incorporating digital agri-food solutions within local commercially viable ecosystems. Developments should therefore target clear revenue models that target the full potential of the market, with example such as subscription-based or fee-for-services only reaching a small fraction [96], [100]. Consequently, public funding will remain a crucial enabler for the development of digital solutions, especially when it has strong public good characteristics, those who target users with limited purchasing power and in local contexts where traditional practices and risk aversion constraint willingness to pay [28], [96]. In general, the fast-evolving digital ecosystem in Africa favours simple adaptive solutions over complex commercial solutions, highlighting the importance of public support and smart finance partnerships in enabling a gradual shift towards sustainable business models.

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4. Policy & Regulation Incentives

Dynamic policies and regulations that targets digital innovations are essential to ensure and enable sustainable competitive markets environments while protecting consumers. Key areas include digital property rights, data ownerships and privacy-related regulations, which must be regularly updated to fit the quickly evolving digital landscape. Enabling regulatory policies and environment can lead to rapid digital expansion, as showcased by the digital-friendly policies in Kenya and Ghana [49], [96].

As of 2025, 76% of the AU has dedicated data protection and privacy legislation in place, and 78% have implemented e-transaction laws to ensure reliable online commercial transactions [61], [96]. However, specific regulation targeting digitalisation in agri-food systems is not widespread and remains uneven across the continent. Commitments by the AU aims to develop comprehensive continent-wide National Digital Agricultural Strategies[19] (NDAS/DAS) in place by 2030, aiming to provide a framework for digital transformation of agriculture [118]. A study investigating the effects of SPS requirements on Cameroon's cocoa export concluded that SPS measures are not as impeding as originally thought and instead could enhance trade and market access for exporting products [101]. However, weak capacity to comply with renewed SPS regulations requires strengthening regulatory and institutional frameworks that are adapted and aligned with **global best practices.** In addition, the government should intensify relationships with stakeholders (farmers/organisations, local and institutional regulatory actors and exporting firms) and prioritise capacity building through knowledge sharing (agricultural extension services) and financial/technical assistance to farmers and exporters to ensure SPS compliance in importing markets [101].

The effective use of a technology depends on the recognition of a global application standard to ensure interoperability and industry-wide consistency. Without shared technical or data standards, custom authorities and other cross-border agencies are unable to efficiently process, very and/or exchange digital trade-related data (e.g., certificates, compliance records), limiting the effectiveness of digital trade facilitation. Continental frameworks and commitments such as the AfCFTA DTP should be enforced by member states within domestic policymaking to prioritise incorporating global application standards into the agri-food chain. Regulatory incentives should address existing power imbalances and structures within (domestic) agri-food systems. A power asymmetry is generally present in the agri-food chain with underrepresented groups, such as smallholder farmers and woman, having limited influence on decision-making, leading to digitalisation policy initiatives not reflecting local needs and realities. Special care should be taken by governments and local authorities to align these local realities in their strategies.

5. Socially Embedded

The adoption and use of digital agri-food solutions is strongly influenced by integration within existing social channels, such as worker's organisations, local communities, self-organising communities and farmer schools [46], [119].

[19] National digital agricultural strategies by the AU and funded by the EU to modernise food systems that improves livelihood, sustainability and efficiency in the chain with digitally enabled solutions.

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First, social influence and peer-based learning play a significant role in adoption. Word-of-mouth communication and collective learning within local communities affect farmers' willingness to innovate or experiment with new solutions [46], [119].

Second, prioritising legitimacy and trust is crucial [95], [119]. Governmental actors and companies should build partnerships that reflect local realities & practices and incorporate trusted intermediaries. Public-private partnerships sharing resources, risks and innovation between governmental and private actors, have proven to be successful collaboration initiatives to bridge the gap between the public and private sector [120], [121]. In this context, user experience and usability should be prioritised over addition of new features.

Third, socially embedded solutions must address gender inequity and power asymmetries while remaining in line with cultural norms and practices [28], [103], [122]. D4Ag solutions affect everyday practices in (rural) farming, including planning, husbandry activities, decision-making and market participation [46]. However, existing gender roles and unequal access to financial resources and digital tools (e.g., mobile phones) limit women and other marginalized group to access and use digital solutions equally. Digital solutions risk reinforcing existing inequalities to users who already possess digital skills and decision-making power without these considerations, highlighting the importance of engaging underrepresented groups and women in the design and deployment process [109], [117]. These technologies must be tailored towards lived experiences, literacy levels and social responsibilities of farmers.

Fourth, socio-factors, local & cultural fit and digital literacy should be prioritised in the design and employment of D4Ag [28], [113]. Differences in age, education, income and familiarity of digital technologies results in varying capacities to adopt and use D4Ag effectively. Additional segmentation within D4Ag solutions, which considers different user groups and varying levels of digital literacy, can improve uptake and inclusivity among farmers [28], [46], [122].

To conclude, D4Ag solutions should align with local (cultural) realities, and be embedded around legitimacy and trust to achieve long-term sustainable adoption and impact.

6. Technology Acceptance

In-line with social embeddedness in D4Ag solution, technology acceptance is shaped by a combination of factors:

First, trust, legitimacy and (perceived) usefulness are important determinants of farmers' willingness to adopt and continue to use D4Ag solutions [95], [111], [113]. Weak data governance on privacy, reliability and unclear value propositions undermine interest and thus uptake among farmers.

Second, D4Ag solutions should be embedded in local communities and context, leveraging existing social channels to benefit from word-of-mouth and collective learning, which are essential drivers for technical uptake [46], [92], [119].

Third, emphasis should be placed on creating human-centered designs, taking into account the socio-cultural, local and digital literacy factors [28], [109], [113]. User experience should focus on reducing effort to operate D4Ag solutions and be adapted to farmers' varying familiarity of digital tools.

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Fourth, D4Ag solutions must be affordable and accessible [28], [92], [96], [113]. This includes availability of hard and software-based (offline) solutions alongside an enabling environment (infrastructure, access to electricity and the internet, regulatory incentives). Increased availability of digital tools is linked to higher uptake among farmers.

Technology acceptance of D4Ag solutions depends on building trust, embedding tools in local realities, human-centered designs and operates in an affordable, enabling environment. Together, these factors ensure that D4Ag solutions are better aligned with farmers' need and daily realities.

4. Key Digital Agricultural Technologies Available

1. Technologies

Digital technologies provide the foundation of digital solutions, tools and services destined for agricultural practices. The following main categories were found in literature:

- **Communication Technologies:** these include mobile phones, SMS, chat applications, internet platforms, network coverage (2G/3G/4G/5G), Interactive Voice Response (IVR) and USSD (Unstructured Supplementary Service Data). Communication technologies are crucial in connecting farmers, provide access to markets and play a pivotal role in digital extension services that offer knowledge, services and support to farmers [48], [92], [112], [123], [124].
- **Fintech:** examples are mobile money, digital banking, digital finance, mobile payment, insurances and other financial services. Financial technology, alongside mobile phone adoption, plays a significant role in providing financial access to smallholder farmers. Fintech facilitates investments, transactions and offers financial inclusion among (remote) smallholder farmers and is a driving force behind the digital adoption in Africa [28], [91], [97], [100], [123].
- **Precision and Smart Farming Technologies:** these technologies include Internet of Things (IoT) devices, sensors, drones (UAV), smart irrigation systems, precision farming, Low Earth Orbit (LEO) satellites, robotics and automation (sensors/computer vision). Although less prevalent among smallholder farmers due to cost, information gaps and availability, precision & smart farming technologies support data-driven automation to optimise and enhance (traditional) farming practices [48], [92], [100], [104], [123].
- **Data Analytics Technologies:** examples are Big Data, Geographical Information System (GIS), Machine Learning, AI, cloud computing and data analytics. These technologies offer informed decision making to farmers and consists of analysing various agricultural input streams (soil moisture, temperature, pH level), providing insights to enhance farm management efficiency.
- **Supply Chain Management (SCM):** encompasses hardware, software, systems and tools that support the management of AVC. SCM innovations aims to improve efficiency, transparency and integration of the value chain through traceability and information sharing among all actors, from input supplier to farmer, processor to retailer (see Table 3).

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Table 3: Supply Chain Management Systems & Digital Technologies.

Type	Definition	Systems	Digital Technologies
Data analysis and visualisation	Analysing business processes, monitoring information systems, planning, data processing/predicting/prescriptive	ERP, ISO, SCOR, Power BI	*Data Analytics Technologies*
Communication between SC actors	Automatic supplier search, procurement, SC process synchronisation, transparency	CRM, SRM, EDI, EDIFACT	social media, marketing
Automation of processes and asset management	Automation of (agricultural) production and inventory management.	robotics, integrated pest management, mechanised planting & harvesting	ERP, IoT, RFID, IoE, digital twins [28], [48], [95], [100], [125], [125].

2. Available services and tools

Disruptive agrotechnology solutions are primarily digital, offering technology adaptations that is tailored to the agricultural sector. Non-digital agrotechnology consists of energy-related solutions (e.g., solar panels), producers and suppliers of bio-products and other non-digital solutions such as aquaponics & hydroponics suppliers and products. The focus in this section is on digital-based solutions, given the predominantly share of recent DATs and the scope of the reviewed academic sources [47].

4.1.3. Digital Extension Services

Digital Extension services (or digital farmer advisory and information service solutions / DES) offer on-demand (pull) or periodically distributed (push) information [1]. The primary aim of extension services is to assist farmers in distributing valuable information to adopt better practices and support in decision-making processes. The knowledge dissemination can range from information on different types of agricultural input-use, planning and farm business management advice to market access and marketing information. Extension service requires data collection from its user, which is used to improve the quality and provide valuable information flows back to agribusinesses. However, information sharing with governmental organisations, NGOs and public institutes also play a critical role in the value proposition of the extension service. Access to timely and accurate information is an important factor in the success of famers outcomes of agricultural extension service on their decision-making and productivity [28]. For example, the Kenian ***iCow*** offers an integrated ecosystem of services and tools to smallholder farmers, providing regular updates and advisory content via mobile phones (SMS, USSD) to its users related to diary and cattle farming [126]. In general, DES utilise digital technologies, such as cell phones and web-based platforms to disseminate agricultural information and provide these advisory services to farmers.

The first wave of digital extension services emerged around 2010 and included general agricultural information and advice to farmers via governmental agencies, NGOs and other

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agency providers (farming information services). DES has become much more sophisticated in its offering, adapting and providing new features and insights tailored to individual farmers and can be classified as the 2nd wave (or recent wave) of DES offerings. Examples of services that offer targeted advice can be categorised in (1) **precision agricultural advice**, (2) **knowledge exchange among farmers through a digital communication platform** and (3) **Farm management software.**

1. Precision agricultural advice (PAA) offers tailored advice and information to the contextual factors of a farmer. Insights in the soil characteristics, remote sensing, detailed weather information, pest diseases, trends and more offers farmers tailored-made solutions to improve its productivity, yield and detect crop diseases early on. A characteristic of precision agricultural advice is its reliance on new emerging technologies, such as drones, satellite images and (IoT) sensors. Despite the highly contextualised advice, the difference between farming information services and PAA can often be minor. Even so, PAA services usually deliver a specific subset of tailored-made agricultural information, indicating that need for further innovation and developments within this sector.

Recent services include ***SOWIT***; a Moroccan-based data-driven farm management solution utilising smart sensors and real-time insights [127]. The recently concluded ***ICT4BXW*****,** a Rwandan based ICT tool that functioned as a pest and disease early warning systems for smallholder banana producers (deploying an app, USSD, and IVR) [128].

2. Peer-to Peer advisory platforms integrate feedback loops between end-users and (user-made) content providers. These platforms provide opportunities to (in)directly connect famers and other stakeholders with one another, offering feedback and solutions to specific challenges and problems farmers are facing. The diversity of the members on peer-to-peer platforms offers diverse knowledge disseminations and creation among (local) farming communities and fall in line with the DES transformation towards more localised, shared interactivity and adaptability among farmers.

Geofarmer is a monitoring and feedback system among (smallholder) farmers to communicate their experiences with a community to manage the crops and farms better. The platform allows content-creation by farmers through text and pictures, which can then be viewed and distributed among local members and experts, providing valuable feedback to its user [109].

3. Farm Management Software provides tools and services to farmers to manage multiple facets of their business. This can include planning/budgeting, farm monitoring, financial management, supply chain management and reporting tools. It shares many similarities with conventional SCM software, but the existing adoption and useability, especially among smallholder farmers, remain limited.

The Kenian ***UjuziKilimo*** offers farmers hardware-based solutions through its SoilPal, a handheld sensor to measure soil characteristics. In addition, the company provides software-based solutions with their farm management system to collect, analyse and visualise farming data, helping the decision-making process of smallholder farmers [129].

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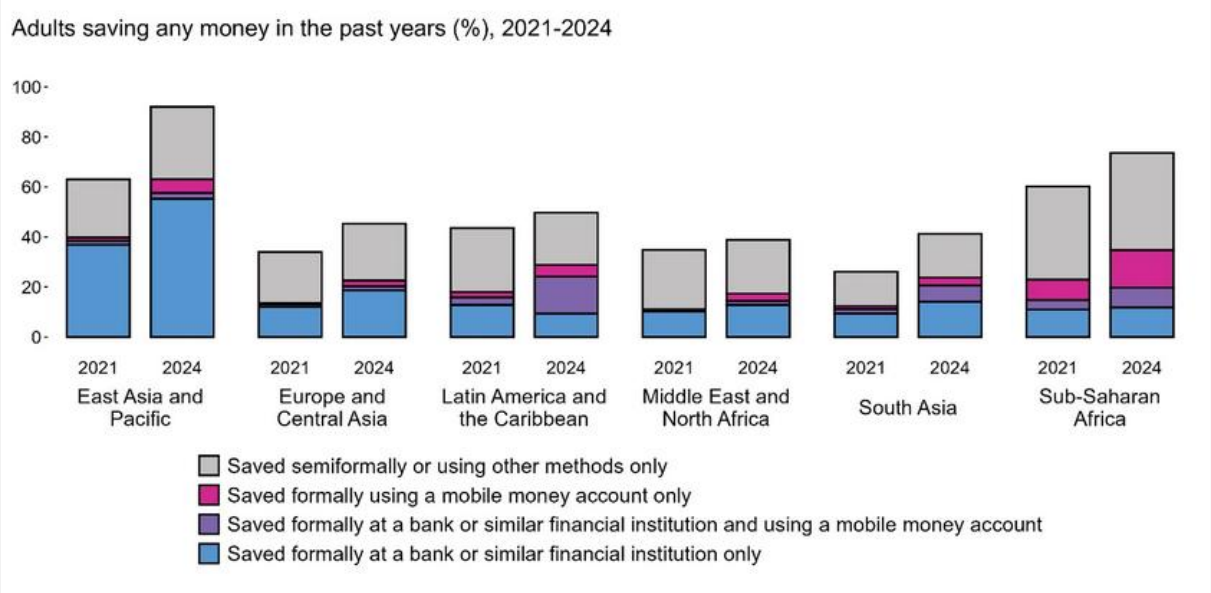
4.1.4. Digital Financial Service

Digital Financial services (or fintech / DFS) provide (agricultural-related) goods and services via digital channels, including smartphones, and other electronic devices. Smallholder farmers face limited access to financial services, including insurances, credit and savings. DFS offer new payment methods that circumvent traditional payment methods and bank systems. DFS can be categorised into 6 main categories: (1) **payment**, (2) **saving**, (3) **credit,** (4) **insurances**, (5) **crowd financing** and (6) **B2B financial analytics services**.

1. (Digitalised) payment methods allow farmers to exchange money with input providers and buyers. Digital payment methods offer lower transaction costs and a more secure methods of payment, mitigating the risks that physical money has (risk of losing it, being stolen etc.). The rise of mobile money payment options showcases a shifting trend in payment methods throughout Africa. According to the World Bank, over a third of people in Sub-Saharan Africa uses a mobile money account, surpassing traditional bank accounts [130]. Despite the importance of mobile money in the region, reliance exclusively on cash remains widespread. The added benefit financial inclusion via bank account ownership, providing benefits such as ownership, safety nets and aid systems, still requires further developments to ensure basic financial services to all.

M-Pesa (Kenya) is a mobile money payment and transfer service, offering a secure and convenient method of payment though its accessibility via SMS or a smartphone app [131]. ***MTN Mobile Money*** is another popular option used in Central & West Africa, offering similar functionalities as M-Pesa, allowing users to buy airtime, pay bills, open saving account, take out a loan and shop online without dependency of traditional banking methods [132].

The ability to open a **2. savings account** offers important opportunities for smallholder farmers. The amount they save and invest in their farms directly translates into improved farming performance and increased profits and is an important step of financial inclusion given the periodic (volatile) farming incomes and often urgent expenses of especially poor smallholder farmers. Popular mobile payment options offer saving opportunities to its users and has been an important factor of the continent's saving behaviour (see Figure 36) [133].



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3. Credit allows farmers, often owning 2 hectares or less, to invest in various opportunities that they otherwise cannot afford directly. Traditional banking methods perceive smallholder farmers as a risky investment, especially in rural areas. According to the CTA Digitalisation report, only 95 of 900 surveyed banks provide financing to smallholder farmers [1], [134]. Digital credit solutions through mobile money bridges this gap by offering credit opportunities that allows farmers for example, to afford farming improving measures that they otherwise cannot afford directly or lack the financial options to do so with traditional banking and payment methods.

4. Insurances are an important factor in farming, considering the various risks associated with the sector (e.g., climate change, bad harvest, pest/diseases, weather events). Without insurances, external shocks can highly influence the farmers operation and wellbeing. Insurances mitigate these risks and farmers adopting insurances for their operation invest more in their farms, healthcare and education [1]. Unfortunately, agricultural livelihood insurances adoption is very low, with estimates of less than 10% of farmers in SSA using such products. Smallholder farmers generally have low levels of understanding and are sceptical of the high cost and slow payout methods of financial institutions that offer these solutions. From the provider perspective, the complex nature of providing insurances to remote farmers makes it less profitable and attractive to conventional insurances. Digital insurances provide opportunities that aim to solve these issues, with faster payment through mobile money and better risk predictability methods (e.g., remote sensing).

Acre Africa is an insurance provider that offers services to build farming resilience and is currently offering services in Tanzania, Rwanda, Zambia and Nigeria[20]. The service offers end-to-end solutions to farmers, assisting them in profiling, market access, access to credit & input, extension services and insurances [135].

5. Crowdfunding refers to a platform that connects farmers to sponsors willing to invest in the farmer's business and activities. The investors generally obtain a share in the farmers business or get paid in agricultural products. These model of crowdfunding overcomes the limited access to credit and offers farmers the ability to invest in their businesses to improve the profitability and farming outcomes through capital investments. Crowdfunding has been a relatively new concept, and the recent emergence indicate the concept is still not set in stone. New rules and regulation in Nigeria in 2021 resulted in two major crowdfunding platforms, *Farmcrowdy* and *Thrive Agric*, to stop or pause their platform [136]. These developments have raised concerns about the legality and long-term prospects of crowdfunding, indicating that these business models and the regulatory frameworks are still evolving.

6. Data analytics for Financial Service Providers[21] is a B2B solutions that offers financial service providers (FSP) capacity on digitalisation of their practices, with data analytics being a key aspect of it. FSP still heavily rely on traditional analogue methods and systems, making it difficult to conduct modern credit risk assessment for farmers. D4Ag providers offer new methods and tools to support the transition towards more digitalised solution, weighing heavily on data-driven solutions to analyse farmers behaviour (e.g., remote sensing, weather data). IT strengthens the FSP operations and expands financial access to farmers.

[20] With on-going projects in Uganda, Ghana, Malawi, Senegal and Mozambique.

[21] Banks, mobile money operators, microfinancing institutions, insurance companies.

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Ensibuuko is a Uganda-based company that provides a cloud-based micro-financing platform, assisting small banking entities to automate their processes, data and payments. It aims to *"build financial inclusion by growing the developing world's digital infrastructure*" [137].

Digital financing services are a key driver to advancements in the African agricultural sector. By providing basic financial services to (rural) smallholder farmers, promoting financial inclusion and support lead to improvements in agricultural productivity and further developments in the sector.

4.1.5. Digital Marketing

Digital Marketing services (or Market Linkage) play an important role to connecting smallholder farmers to high-quality farm inputs, production and post machinery. In addition, it often includes mechanisation services, and access to buyers, reducing transaction costs.
Digital marketing can be categorised into four main dimensions: (1) **Agri Input and Food E-Commerce services**, (2) **Mechanization services**, (3) **Agricultural E-Marketplaces** and (4) **Digitally Enabled Value Chain Integrators.**

1. Agri-input and Food E-Commerce services are online retailers for agricultural produce and offer urban consumers the ability to order agricultural produce or farmers access to agricultural input (providers). Order fulfilment is done online, and the delivery of the services and goods generally relies via shipment or pick up via brick-and-mortar stores. Food e-commerce requires fully digital integration of various supply chain processes (e.g., cold chain, packaging, distribution, online platform) and is therefore in practice meant for small consumer target groups. Agri-input offers farmers access to various agricultural input, such as seeds, fertilisers, machinery and other equipment. Nevertheless, linking farmers directly to end-consumers cuts out intermediaries, generating more value for the farmer and the D4Ag provider. The increasing number of people living in cities offers potential of a growing sector in the near future.

Jangolo (Cameroon) is an online agricultural platform that offers a variety of services, including agri-input services to farmers [138]. ***Khula!*** is an agri-tech company based in South Africa and connects farmers, food buyers and agri-input suppliers through its online platform [139].

2. Mechanisation services provide farmers access to farm machinery and equipment. Mechanisation in the agricultural sector improves farm productivity through machinery and is an essential driver of agricultural transformation. However, farmers utilising farm machinery and equipment is the lowest of any region globally [1].
Mechanisation services provide opportunities to farmers to rent farm machinery to assist in harvest or prepare land, improving agricultural productivity and output. The services are generally offered via digital platforms and tools, addressing several of the major mechanisation uptake constraints and is a promising D4Ag solutions to transform the sector.

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Hello Tractor is a digital platform that connects tractor owners to farmers through a shared economy / pay-as-you-go service model and is currently operating in Nigeria, Kenya, Rwanda, Uganda and Ethiopia [140].

3. Agricultural E-Marketplace connect individual sellers and buyers of agricultural produce together, giving them the opportunity to transact. The service itself requires little to no human intervention and can help solve the problem of the inefficient and fragmented agricultural markets.

AgroMall (Nigeria) connects smallholder farmers and agribusinesses together by offering digital solutions and has incorporated an online marketplace for agricultural products and inputs [141].

4. Digital-Enabled Value Chain Integrators combine digital tools and human agents to connect agricultural markets. The service aims to formalise the fragmented value chains in agriculture, and can be classified into three key variants: (1) Input Market Integrators, connecting farmers to agricultural-inputs, (2) Off-take Market Integrators, connecting farmers with (contractual) purchase agreements from buyers, groceries and other aggregators, (3) End-To-End Market Integrators, integrating input-suppliers and off-take agreements alongside financing and advice, offering a fully integrated package to the farmer.

EzyAgric (Uganda) is an end-to-end farmer solution, offering services such as planning, input, market linkages and production [142].

Digital market platforms represent a new way for farmers to incorporate input-suppliers and markets with buyers, traders and other (end-)consumers, harmonising the generally fragmented agricultural value chain for farmers.

4.1.6. Supply Chain Management (SCM)

SCM coordinates all activities within the (agricultural) value chain, ranging from input procurement to distribution, logistics followed to the purchase/delivery of the end-consumer. Agribusinesses[22] that have off-take or other informal agreements with smallholder farmers can incorporate SCM to better manage their relationships to make their business (and in turn value chain) more efficient, safe and profitable [1], [96]. Agribusinesses can help incorporate smallholder farmers into their network through SCM tools. The SCM solutions depend on the actor of the value chain, but in general upstream – and downstream suppliers that incorporate SCM tools benefit from lower transaction costs and increased transparency and efficiency.

D4Ag SCM solutions offer tools and other in-house solutions to track and manage important parameters of agricultural processes and can be divided into four main categories: (1) **Traceability and Certification Solutions**, (2) **Input Quality Assurance**, (3) **Logistics** and (4) **ERP systems.**

[22] Upstream: input-suppliers, processors, traders. Downstream: cooperatives, wholesale/export, grocery store

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1. Traceability and Certification Solutions are digital tools to track produce from farm-to-fork and assist in documentation of standards/certificates and digital record keeping of actors. It offers improved transparency, efficiency and accountability in the value chain. The increasing global demand of transparency among the agricultural value chain offers various opportunities and drives adoption of such tools. Upcoming EU legislation such as the EUDR and the various SPS certificates and documentation requirements for trade purposes benefit from traceability and certification SCM tools. Food Safety and Standards require elaborate documentation of tracking food products to ensure proper food safety issues such as recalls in case of contamination and other issues among the value chain.

TraceX Technologies (Ghana/Univision) offers end-to-end traceability SCM tools (blockchain-powered) and assists in complying with regulatory compliances (certificates/documentation) and harmonising the various agricultural actors into a single platform [143].

2. Input Quality Assurance helps agribusinesses to protect their brand integrity, combat counterfeits and allows farmers to verify the authenticity of agricultural inputs. The varying demands and counter fakes of agricultural inputs, such as seed, fertilisers and pesticides, undermines the quality assurances of agribusinesses and is considered an important barrier that prevents the advancement of the sector. Fake and/or modified agricultural inputs, but also expired or diluted products, harmful substances and a lack of reliable verification methods create challenges among the agricultural value chain. Unreliable agricultural inputs lead to lower yields, less revenue and create mistrust among farmers / agricultural actors. In addition, fake commodities can push out legitimate products on the market due to lower (agricultural input) prices. Digital input quality assurances can assist in combating counterfeits, improving trust among the chain and reducing the economic and productivity losses by providing farmers quality assurances that meet certain (pre-approved) standards.

Sproxil is a health tech company operating in Nigeria and Kenya that combats counterfeits products through offering consumers (mobile-based) product authentication services to check the validity of products (medicine) to combat counterfeits [144]. Sproxil Informer is a track-and-trace platform that provides end-to-end visibility of products across the (agricultural) value chain, offering better traceability and brand protection measures for (agri)businesses.

3. Logistics is an essential process in any value chain. It tracks, monitors, coordinates and optimises (inventory) distribution of goods across the value chain. The fragmented value chain in Africa, generally suffering from poor infrastructure, limited storage and high post-harvest losses, remain a major challenge to the sector. SCM logistic tools allow agricultural actors to improve the value chain visibility, offering valuable insights to improve efficiency and optimise the distribution of their products.

WeightCapture (Capture Solutions, UK) offers digital tracking solutions of raw goods, ensuring full and accurate traceability by integrating end-to-end traceability [145]. Operating in Kenya, Nigeria and Côte d'Ivoire, the company also provides other services to help agribusinesses comply with regulations such as the EUDR.

4. Enterprise Resource Planning systems provide a fully integrated platform with the SCM digital solutions mentioned above. These systems combine various aspects such as logistics, procurement, human resources, traceability and business intelligence. It extends beyond the

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various standalone (digital) tools and offers multiple cost-efficiency benefits but remains primarily used by larger entities in the agricultural value chain. An interview performed by WP3 with a notable tea producer in Rwanda highlighted that the implementation of an ERP system based on Microsoft Dynamics 365 was currently in progress, citing that automation of record-keeping of production processes and integrating interoperability standards were the main driver of ERP adoption.

eProd (Kenya) offers a supply chain management ERP systems to agricultural companies, allowing them to structure farmer data, monitor production, improve market and finance access and ensure improved traceability [146].

SCM tools are a crucial element in (maturing) supply chains, offering various benefits that assist in streamlining agricultural processes. Despite the various challenges facing the African agricultural sector, demand by agribusinesses to comply with regulations and standards issued by for example the EU, illustrate a clear need for advancing SCM tools that fits the African context. The emergence of D4Ag start-ups offering SCM solutions to agribusinesses illustrates the advancing nature of the sector.

4.1.7. Digital Farm Management Tools

Digital farm management tools assist farmers in various agricultural processes, including planning, monitoring and managing farm operations. These digital tools often combine data-driven processes to support the decision-making process of farmers. However, (internet) access, digital illiteracy and costs prevent widespread adoption of these tools despite the documented benefits. Nevertheless, the previously mentioned advancements in D4Ag solutions and mobile phone adoption rate offer new opportunities and solutions to smallholder farmers, especially in rural areas and are an important tool to offer informed decision making and adoption of precision practices to smallholder farmers. These tools therefore consist of various aspects of the previously mentioned digitalisation solutions.

Examples of D4Ag Farm Management tools consists of:

- Crop/soil health monitoring
- Farm mapping/planning
- Remote sensing
- Advisory support
- Risk management

One Acre Fund is an agricultural service provider that supports smallholder farmers with training, financing and advice to help them increase their yields and profitability.

4.1.8. Sustainability

D4Ag solutions include sustainability practices in their solutions, reflecting the growing importance of environmental and social standards in the challenges the continent faces, such as climate change and trade practices. Changing regulations and more stringent requirements, particularly in areas such as deforestation and carbon emissions, forces agribusinesses to comply with (new) sustainability standards. Digital extension services play a key role in this transition, promoting sustainable agricultural practices, such as water-efficient irrigation system and resilient soil and crop varieties to smallholder farmers. Other D4Ag solutions also

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contribute to the sustainable transition requirements by integrating farm, market, and environmental data to help farmers make better decisions to comply with sustainability standards.

In summary, D4Ag solutions increasingly include sustainable practices in their offerings, supporting farmers in building a resilient and profitable business. The changing global environments pushes agribusinesses to comply with these new standards, transforming the agricultural sector into adoption of more resilient and sustainable practices.

The following section provides an overview of the digital services across the continent.

4.1.9. Overview D4Ag services across the continent

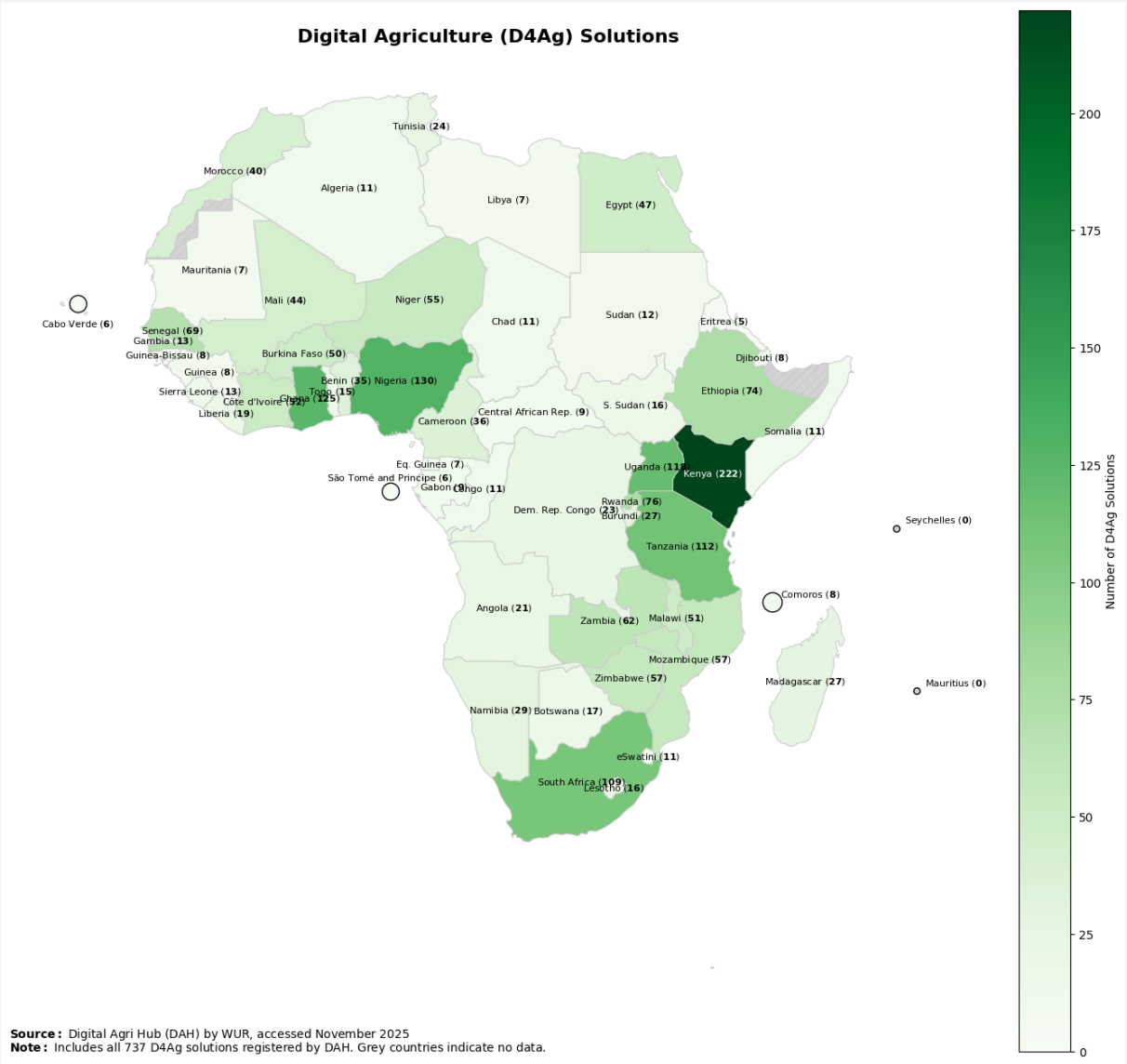


Figure 37: Overview Number of D4Ag in 2025 (own illustration) [147]

The Digital Agri Hub (DAH) tracks various D4Agsolutions across the continent. **West- and East Africa** show the largest concentration of D4Ag solutions, with Kenya standing out as having the highest number of D4Ag solutions (see Figure 37) [147]. The strong tech ecosystem

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supported by the government and the good digital infrastructure allows Kenya to bring various D4Ag solutions to market.

In **West Africa**, Nigeria and Ghana are primary drivers of D4Ag solution, supported by its developed mobile phone market and strong agricultural export economies.

Egypt and Morocco offer relatively more D4Ag solutions compared to Algeria, Libya and Tunisia in **North Africa**.

In **Southern Africa**, South Africa remains the dominant hub of D4Ag Innovation, with its mature trade market and the need to comply with evolving global requirements acts as an important driver of new innovative digital solutions.

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Figure 38: Descriptives D4Ag solutions. (Source: digitalagrihub.org) [147]

The D4Ag solutions consists primarily of farm management and advisory services, followed by market linkage solutions and saw a peak of new start-ups registrations around 2017 (see Figure 38). Most of the D4Ag services utilise data-driven methods and business intelligence though the sector showcases a variety of different technological approaches across the 737 D4Ag solutions. From available D4Ag solutions, the user-base is targeting primarily smallholder farmers, followed by youth and women.

Finally, many of the solutions are developed and deployed by agritech or agribusiness, with governmental-led solutions remaining relatively scarce (see Figure 39).

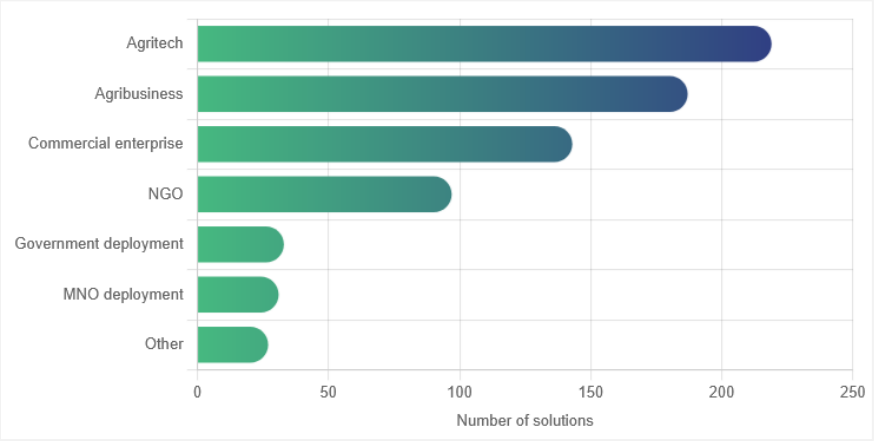


Figure 39: Distribution of D4Ag solution Providers. (Source: digitalagrihub.org) [147]

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4.2. Case Study I: Enhancing Cassava Food Safety Standards through Digitalisation

4.2.1. Background Cassava production in Africa

Cassava is a staple food for over 800 million people worldwide, and is an important source of protein, vitamins, and minerals [148]. The roots are consumed primarily, but in some parts of Africa the leaves are also eaten. Cassava is a climate-resilient crop and may be better able to withstand climate change compared to other staple foods, such as maize, rice or millet [149]. Jarvis et al. (2012) drew similar conclusions, indicating that cassava could play an important role as a staple food in many parts of Africa due to its climate-resilience properties [150].

Alongside the importance of cassava in African diets, the crop is an important export (potential) product for African producers. Spain, France, and the United Kingdom are main import countries of cassava in the EU, contributing to their large populations of African descent and thus potential consumers [151]. Cassava is mainly exported as flour, starch, chips, or pellets [152]. The cassava export grows by about 15% per year, similar to the export curve of sweet potato two decades ago. As cassava is not suited for cultivation in Europe, European consumers are solely dependent on cassava imports [151].

During transport and consumption, cassava should be handled with care. Improper care of cassava has been associated in cases of cassava cyanide poisoning, including fatalities in Nigeria [153]. Cassava roots contain toxins, like cyanide, and heavy metals, such as lead. Proper processing is required to ensure a reduction of these substances to a permittable safe level for human consumption.

In the EU, food safety regulations are in place that restricts the maximum levels of contaminants in food products. Specifically, **EU Regulation 2023/915** of April 25th, 2023, imposes maximum levels (ML) of certain contaminants in food and repeals the previous regulation on ML in contaminants (Regulation 1881/2006) [154]. The ML of lead is 0,10 mg/kg for root and tuber vegetables, such as cassava roots. As of right now, there is no set ML of lead in cassava flour. The ML of hydrocyanic acid (cyanide) is 50,0 mg/kg for cassava root fresh and peeled, and 10,0 mg/kg for cassava flour. The regulation affects access to the EU market for African cassava exporters specifically, requiring the implementation of new processing techniques and continuous monitoring of new regulations to ensure access to EU markets. A cassava producer in Rwanda expressed the difficulty to fit the sudden strict EU regulation guidelines and the resulting rejection of a cassava export batch, while indicating the economic importance of the EU market for the company compared to other markets.

The new imposed regulation, which came in effect in April 2023, requires further investment in the cassava food safety system to identify and assess critical food safety levels. The implementation of control points (CP) and critical control points (CCP) systems from the Hazard Analysis and Critical Control Point (HACCP) framework offers a structured approach that assists in complying with the renewed legislation through its international-recognised standardisation of food safety monitoring and documentation. Food-related measurements from CPs and CCPs may results in improved transparency and traceability throughout the cassava supply chain, and this information can be communicated effectively by converting analogue food-safety information (pen & paper to digital spreadsheets) digitally, helping to

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mitigate food safety risks and rapid identifications of contaminated batches in the event of food recalls.

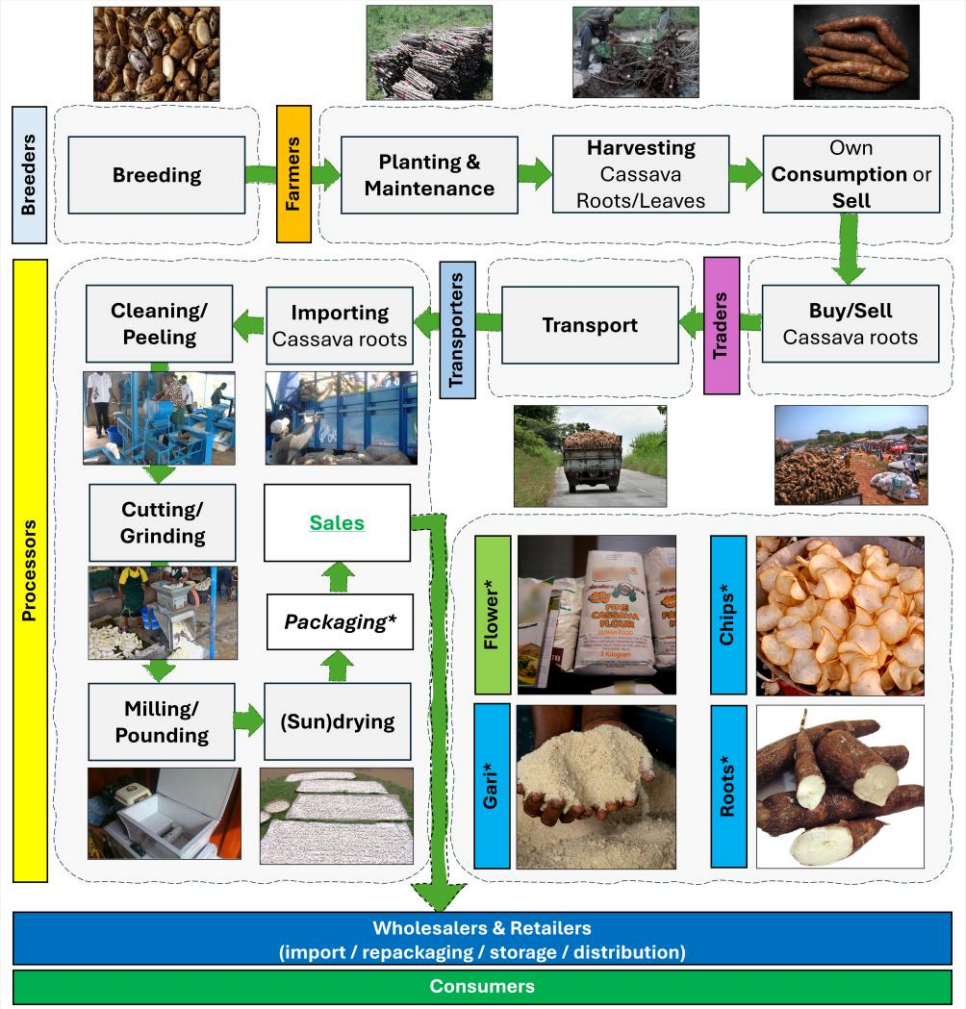


Figure 40: Exemplary cassava supply chain for the production of cassava flower based on Pingmuanglek et al. (2017) and Tambun & Manik (2021) – own illustration (see Annex VIII – Sources of Images) [155], [156]

4.2.2. Cassava Supply Chain: Primary Actors and Key Stages

Stakeholders in the cassava supply chain include breeders, input dealers, farmers (smallholder, group, and commercial), transporters, farmer-processors, processors, wholesalers, corporate companies, marketers, retailers, and consumers.

Key stages in the cassava supply chain include **breeding**, **planting**, **harvesting**, **processing**, **distribution**, and **consumption**. The cassava products vary by end use: fresh roots, flour, gari, porridge, and starch/tapioca. Each product has different processing steps that impact contaminant levels such as cyanide and lead [157], [158]. For example, processing cassava flour involves peeling, washing, grating, pressing, drying, and grinding, while gari production includes fermentation and roasting [159]. These variations in processing methods directly influence the contamination levels in cassava products, highlighting the importance of targeted intervention among the different processing steps in the cassava supply chain.

Figure 40 shows an example of a cassava supply chain based on Pingmuanglek et al., (2017) and Tambun & Manik (2021) [155], [156]. After the breeding, growing and harvesting

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processes at the farmer level, the trader is an important link that impacts the final end product: either cassava starch (tapioca), cassava flour, or cassava root. Figure 40 shows an example of a cassava supply chain based on Pingmuanglek et al., (2017) and Tambun & Manik (2021). The trader is an important link in the chain after farming-related activities, influencing the final state of the (unprocessed) cassava roots, and generally consists of trading cassava starch (tapioca), cassava flour, or cassava roots.

Since the cassava root is not subjected to a lengthy production process, higher levels of cyanide and lead are generally observed compared to cassava flour or starch. The cassava flour is washed, fermented, soaked, and dried, resulting in lower cyanide – and lead levels due to various steps that reduce these contaminants. For the tapioca processing, the washing, rasping, extraction, separation, dewatering, and drying help reduce the cyanide and lead levels [155], [156]. Despite these production steps, exceeding of maximum levels of cyanide and lead levels still occur.

Continuous measurements of cyanide – and lead levels during the production process are important steps to predict the contaminants level in the final product. These measurements contribute to the monitoring in control points (CPs) or critical control points (CCPs) and are key in the cassava food safety system [160].

4.2.3. Managing Food Safety in Cassava: CPs, CCPs, and the HACCP Framework

CCPs are part of the hazard analysis and critical control points (HACCP) approach (see Figure 41) [161]. A HACCP concept encompasses guidelines for setting up a control and assurance system of food safety hazards in food production processes, following contaminant limits stated by law of the product. The concept is built around seven key concepts:

1. **Hazard analysis**
2. **Determining of critical control points (CCPs)**
3. **Establishing critical limits CCPs**
4. **Establishing monitoring system per CCP**
5. **Establishing corrective actions**
6. **Developing verification procedure**
7. **Establishing documentation and record-keeping**

For cassava flour, the Maximum Level (ML) of lead has not been established, whereas for the root vegetables, the ML is 0,10 mg/kg. The ML of cyanide is 50,0 mg/kg for cassava root fresh and peeled, and 10,0 mg/kg for cassava flour [154]. There can be multiple CCPs per hazard, each with their own critical limits. To determine critical or non-critical control points (CP/CCPs) in food production processes, a CCP Decision Tree can be used to identify potential points of control based on the **severity** and **likelihood** of food safety risk (see Figure 41) [162].

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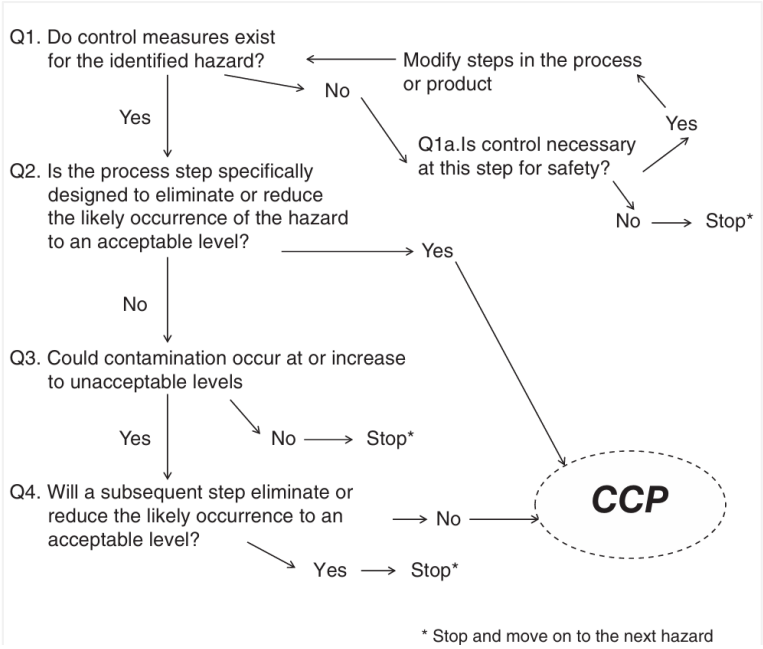


Figure 41: Example CCP Decision Tree (Source: Codex Alimentarius Commission) [162]

Control points and critical control points are crucial for food safety in the cassava supply chain. CCPs include controlling for pH levels during fermentation, duration of the fermentation process, and water quality [163], [164]. CPs include practices ensuring cassava tubers are free from mould, and maintaining hygiene during processing [163]. A Prerequisite Program (PRP) in HACCPs offers guidelines of basic activities/conditions to prevent hazards from occurring or contamination of the item. An example of the PRP for potable water includes cleaning and sanitizing of processing tanks and surfaces that come into contact with the water used for processing of cassava.

The HACCP concept provides guidance on identifying CCPs or CPs, establish critical limits, and monitoring compliance along the supply chain. Information gathered from HACCP, CCPs, CPs, and critical limits should be clearly communicated to next production steps to ensure consistent food safety throughout the entire processing steps. The integration of digital measurements, such as digital traceability and CCP-aligned digital monitoring of production parameters, offers improvement in the information flow and transparency across supply chain actors. In addition, digital traceability measurements of agri-food supply chains offer benefits such as improved agility in case of recalls, particularly in the rapid identification and traceability of contaminated batches (known as the mandatory one-step back, one-step forward traceability approach in the EU). The following section offers an overview of the HACCP framework to address cyanide and lead poisoning in the cassava supply chain and highlights the role of (digital) information systems to support monitoring, sharing and communication of CCPs.

4.2.4. Cyanide and Lead Contamination: Sources and Monitoring

Cyanide occurs naturally in cassava, including *cyanogenic glucosides* (plant defence compound), *cyanohydrin* (breakdown products when plant defence is triggered), and free *hydrocyanic acid* (poisonous acid released when plant cells are damaged). The existence of these substances complicates accurate measurement [165], [166]. Cyanide levels are affected by genotypes, environmental factors, (late) harvesting period, drought, and insufficient

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processing [167], [168]. Lead contamination is primarily associated with soil pollution near cement plants, mining activities, and industrial zones [169], [170], [171].

Cyanide monitoring methods include *alkaline titration*, *neutron reflection*, and *corrin-based chemo sensors* [172], [173], [174]. Lead is monitored using *atomic absorption spectrometry* [170], [171]. The Rapid Alert System for Food and Feed (RASFF) notifications show that elevated cyanide and lead levels have led to recalls or warnings in the EU, which was the case in Ireland in 2024 and Germany in 2023.

Based on the identified contamination sources and monitoring methods, the following CCPs were identified for monitoring and reducing food safety risk based on the academic literature in Tabel 1.

Tabel 1: CCPs Cassava Production

Actor	Processing step	CCP	Critical limit
Farmer	Breeding	No (prerequisite program)	Cassava-breed dependent
Farmer	Planting	Yes	Pb (lead) testing of the soil
Processor/Farmer	Fermentation	Yes	Duration between **72 – 96 hours**
Processor	Soaking/steeping	Yes	Soaking: **pH 4 – 4.2** Residual soaking: **pH < 3.8** Drinkwater: **pH = 4.7**
Processor	Toasting/roasting	Not yet established	Temperature-dependent [175]
Processor	Drying	Yes	Temperature: **140 ºC – 180 ºC** Moisture: **< 14%**
Processor/Retailers	Packaging/storing	Yes	Packaging: jute sacks lined with polypropylene Temperature stored: **< 30 ºC** Humidity stored: **< 60%**

Information Systems

Information systems are essential in effectively monitoring, capturing and sharing of food safety parameters during the processing steps. Continent-wide initiatives (e.g., World Health Organization Africa, and Good Agricultural Practices GAP) alongside EU legislation on food safety (e.g., the mandatory one-step back, one-step forward approach) highlight the importance of incorporating increased documentation and monitoring to improve food safety in Africa, comply with food safety standards and audits, and avoid EU trade obstacles for (cassava) exporters. The HACCP guidelines provide the structure to manage and document food safety practices using (modern) information systems. Digitalisation of documentation, record keeping and monitoring practices regarding food safety offers improvements in these aspects by automating and storing required food safety information via digital means, such as storage in internal databases after converting pen/paper measurements into digital

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spreadsheets or ERP systems. Incorporating HACCP principles in production processes creates requirements on data governance and sharing practices, both for internal and external use (business partners, audits agencies).

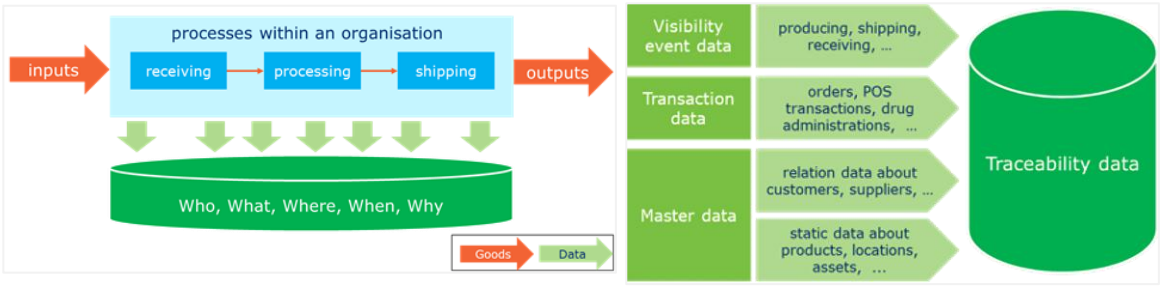


Figure 42: (L) Generation traceability data and (R) Sources of traceability data (Source: GS1 Global Traceability Standards) [176]

Implementation of HACCP principles involves aligning information systems and data sources with business processes to allow capturing, sharing and tracing of important food-safety parameters (traceability data). Specifically, organisations can build upon the general principles of traceability data frameworks, adapting and designing these with company and HACCP specific realities (see Case Study III and Chapter 5 for a deep-dive). A general data framework consists of identifying and aligning key business processes, including establishing the Who, What, Where, When and Why (see Figure 42 (L)) [176]. A critical component of data capture solutions is the use of common language and standards, which allows streamlining various business – and data differences within and between organisations. This further enables interoperability of data exchange between upstream and downstream partners. Traceability data consists of four sources and these together provide the necessary information to understand the full context of traceability data: (see Figure 42 (R)) [176]:

1. **Master data** refers to the single source of common business data and is used across all systems, applications and processes within an organisation. *Static master data* relates to relatively stable core entities, such as products, partners, and assets. *Master relation data* describes the organizational supply chain partners, typically specified by product (category) and location.
2. **Transaction data** refers to recordings of formal business transactions and is generated as part of business processes (e.g., Point of Sale POS, shipments, payment or owner transfers).
3. **Visibility event data** captures completion of business steps specifically for visibility and traceability purposes and generates data related to the 5 W's (who, what, where, when and why) of physical or digital entities after competition of business process steps.

HACCP principles combined with a proper traceability framework enable cassava exporters to incorporate and improve food safety practices, particularly regarding the risk associated with cassava consumption, in-line with international-recognised food safety principles. The principles and framework provide a structured foundation to the design and evaluation of traceable food-safety monitoring systems, that comply with both domestic and EU food safety legislation.

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4.2.5. Conclusion

Cassava is a staple food in African diets and has the potential to gain even more importance in the future due to its climate-resilience properties. Nevertheless, cassava food safety is influenced by both naturally occurring compounds and environmental factors, such as lead present in the soil. Proper steps should be taken across the value chain – ranging from soil testing, controlled fermentation, soaking and packaging/storing – to minimise health risk. Specifically, farmers and processers should prioritise implementing HACCP-principles during key steps in the processing of cassava to minimise risks and adhere to critical limits in the planting, fermentation, soaking, toasting, drying and packaging step. Current EU legislation on food safety standards creates barriers for cassava exporters to enter EU markets, highlighting the need for harmonised food safety standards – including digitalisation of CCP monitoring, traceability and reporting systems – to facilitate and elevate cassava production and trade in Africa.

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4.3. Case Study II: From Leaf to Cup - Tea Quality Metrics and Digital Traceability Solutions in the African Tea Supply Chain

4.3.1. Tea Production, Grades and Market Significance

Tea is a major cash crop in several (predominantly Kenya, Malawi and Uganda) African countries and plays a critical role in rural employment and export-earnings, with the EU being an important high-value market. Tea is one of the oldest beverages and is after water the most consumed drink in the world [177]. Derived from cured tea leaves of the perennial plant *Camellia sinensis,* tea is produced in a wide variety of types, with the main types ranging from black, green, dark, oolong and white tea. The African tea producers produce primarily black tea, grown mostly in high-altitude regions with sufficient rainfall and cool temperatures.



Figure 43: Primary Grades black tea (L) and a tea plantation (R), documented during fieldwork in Rwanda.

The grade, quality and particle size of dried tea leaves, commonly[23] **BP1**, **PF1**, **PD** and **Dust1** of most in-demand grades, are the main influencing factor on the final price paid at auction (see Figure 43). A lack of consistent quality control measures throughout the production process has led to recurring instances of large quantities of unsold tea that did not meet quality standards at auctions. Tea is sold mainly through intermediaries on auction platforms, where expert tastings play a key role in determining quality and reveal deficiencies that begin at the farm and are further compounded during processing. Improvements in quality control measures, both during the harvesting and processing of the leaves, can significantly affect these grades, resulting in higher earnings by tea producers [178].

As global (EU) markets increasingly require new standards and requirements on quality attributes, ethical sourcing, and certificates compliances (e.g., EU pesticide residue limits (MRLs), Rainforest Alliance or Fairtrade), the need for new innovative digital solutions on traceability and quality control is increasing. This case study explores how quality control and information requirements can be implemented in the value chain through quality control points (QCPs), following HACCP principles and traceability frameworks discussed in Case Study I, at each stage of the supply chain. While the HACCP principles were originally created for critical control points, QCPs can be determined with the same decision tree but requires slight reframing – specifically Q2 – to fit quality instead of critical food safety (see Figure 41 in Case Study I). Following academic findings from a semi-structured literature review, an overview of

[23] Orthodox black tea grading system: Broken Pekoe 1 (**BP1**), Pekoe Fannings 1 (**PF1**), Pekoe Dust (**PD**), Dust Grade 1 (**D1**), with PF1 being the most popular for Lipton-style blends/tea bags in Europe.

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an exemplary tea value chain is provided, followed by a framework on found QCPs, critical limits, and the role of digital information systems to improve tea quality metrics.

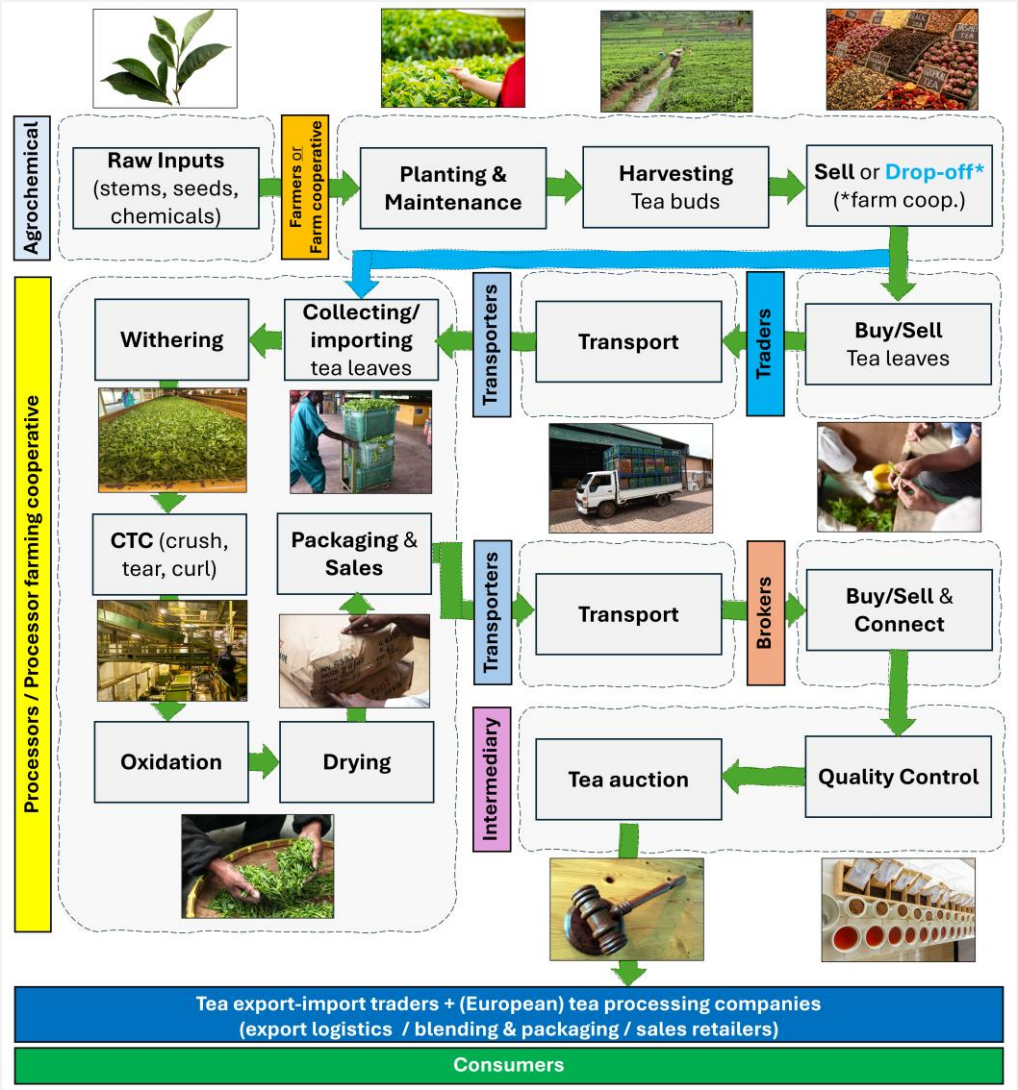


Figure 44: Exemplary Tea Value Chain, adapted from Foster & Graham (2024) – own illustration (see Annex VIII – Sources of Images) [179]

4.3.2. Tea Supply Chain: Primary Actors, Key Stages and Quality Attributes

Figure 44 showcases an exemplary tea value chain adapted from academic literature, illustrating key stages in tea production from leaf to cup [179]. The primary actors in the chain include input suppliers, tea growers, processors, traders and brokers, intermediaries (auction platform, banks, warehouses), tea export-import trader responsible for export logistics, and downstream (European) tea processing and consumer markets. In African markets, tea processing companies often own both tea plantations and processing factories (vertical integration), organised through (tea) farm cooperations. These companies employ local workers and/or cooperate with local smallholder farmers growing tea. Tea auctions act as intermediaries and play a significant role between upstream and downstream actors in the chain. The Mombasa Tea Auction in Kenya serves as a key example, handling approximately ¾ of Kenya's black tea sales, with Uganda accounting for 16% and other East-African producers making up the remaining 12% [180].

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Key stages in the tea supply chain include **growing/harvesting, processing, blending and packaging, trading and exporting.** Quality attributes are mainly affected in the **harvesting** and **processing** stage, with later steps (e.g., transport, blending and packaging) affecting quality preservation as opposed to quality formation. The following section explores key parameters influencing tea quality in the harvesting and (post-)processing stage.

Quality attributes black tea

Table 4: Quality attribute indicators of black tea

Quality Attribute	Key Chemical Substance/Indicator	Description
Colour (Infusion/Liquor)	Theaflavins (TFs), Thearubigins (TRs)	TFs give golden-yellow; TRs give orange-brown. Darker colours indicate higher-quality tea [181], [182], [183].
Turbidity/tea cream	Theaflavin gallates, caffeine	Determines cloudiness or opaqueness. TF gallates and caffeine increase tea cream and turbidity (cloudiness) [184].
Taste	Thearubigins (TRs), Theaflavins (TFs), Caffeine, and Polyphenols	TRs add strength and mouthfeel; TFs add briskness and astringency [183], [184]; caffeine adds tanginess [182]; other compounds influence aroma [181].
Astringency	Theaflavins (TFs), Thearubigins (TRs), and Polyphenols (PP)	Produces the dry, puckering sensation in the mouth [183].
Briskness	Theaflavins (TFs) and Caffeine	Gives a lively, refreshing quality [183], [184].
Body/Mouthfeel	Thearubigins (TRs) and High Polymerised Substances	Provides fullness or tactile sensation [184].
TFs	0.5 – 2 % of dry leaf weight (Wright et al) [185]	
TF – TR ratio	1:10 (Deb & Jolvis Pou, 2016) [186]	

Tea quality can be categorised into 6 sections: **colour**, **turbidity/tea cream**, **taste**, **astringency**, **briskness and body/mouthfeel** (see Table 4: Quality attribute indicators of black teaTable 4) Table 4). In general, theaflavins (TFs) and thearubigins (TRs) are main substances affecting tea qualities and should ideally occur with a TF – TR ratio of 1:10 [185]. TFs should ideally make up 0.5 – 2% of the dry leaf weight [186].

Harvesting

During harvesting of tea leaves, important determinants which affect quality include the plucking standard, interval of plucking, quality of the green leaf itself and the geographical location [187], [188]. In addition, the cultivar of the plant is also a major determinant on the final quality. In line with the Codex Alimentarius (international recognised collection of food standards), these determinants can be classified as Quality Control Points as deviations in these steps cannot be corrected at a later step.

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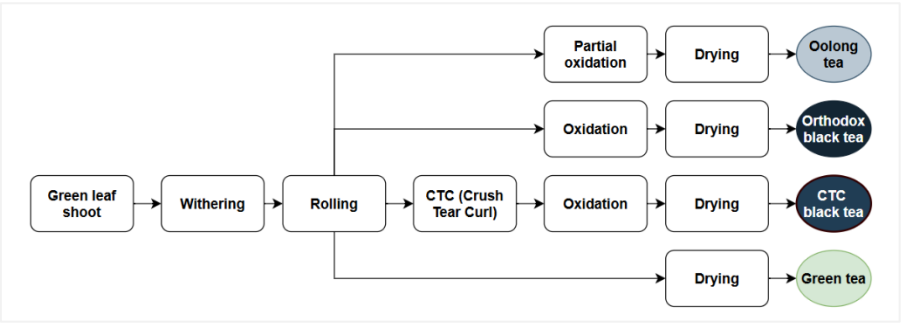


Figure 45: Processing steps of various tea types. (Source: Jolvis Pou et al., 2019) – own illustration [182]

Processing

Processing involves multiple steps to transform the (fresh) tea leaves into market-ready tea products (see Figure 45) [182]. Several steps in processing of the tea leaves are essential, since corrective action are not possible at a later stage. Withering, oxidation, and drying were found to be QCPs. During **withering** of the leaves (reducing moisture content to make the leaf flaccid and pliable), the moisture content must be controlled and should usually reach levels between 66-70%, although cultivar-specific limits exist [189]. A moisture level below 65% is detrimental to quality. **Oxidation** (broken tea leaves reacting with oxygen; changes colour from green to brown) requires monitoring of temperature, time-duration, relative humidity - and oxygen levels [190]. The final processing step consists of **drying the leaves** to lock in the flavour and make it shelf-stable with a final moisture level between 2 – and 3%. During this process, controlling for temperature, time-duration and moisture content is crucial [189], [191].



Figure 46: Bulk tea consignment, documented during fieldwork in Rwanda.

Post-Processing

Packaging the dried tea leaves is a crucial step and starts after the drying process. Tea processing companies that do not operate their own consumer brand ship final tea batches in bulk consignments meant for sale at auction or through other intermediary channels (see Figure 46). The mixing of different tea varieties and quantities is generally performed after the auction process by tea processing companies at the end of the chain, destined for local markets that fit consumer preferences (e.g., loose tea, tea bags). While blending is a key step to meet consumer expectations, the absence of a specific measurable quality criterion makes this step not a QCP. Nevertheless, a method such as scientific blueprinting of flavour profiles (e.g., specific flavour, aroma) can be utilised for monitoring quality in the finished tea product [190].

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4.3.3. Managing Quality Control in Tea: QCPs and the role of Digital Information Systems

Tea quality attributes, which cannot be modified in a later (processing) step, are primarily influenced during the growing, withering, oxidation and drying stage (see Table 4). However, cultivar-specific – and geographical locations (e.g., influenced by altitude, climate change, drought or rainfall) are also important determinants on the quality of the finished tea product, but does not fit the HACCP / Codex Alimentarius (as described in Case Study I) guidelines on likelihood and severity. Geographical location and the cultivar used cannot be corrected during the production cycle or brought back within critical limits. Nevertheless, the cultivar choice does enable quality and can therefore be seen as a strategic choice under a prerequisite program (PRPs) or Good Agricultural Practices[24] (GAP). Legal acts, such as the Kenya Tea Act, prohibits growing of tea in unsuitable locations and offers a handbook that offers guidance on the required altitude, humid growing, specific soil pH values, fertilisation and canopy management (e.g., shading, pruning) [192].

Table 5: QCPs of tea

Actor	Processing step	QCP	Critical limit
Farmer/Processor	Location, cultivar	No (PRP/GAP)	
Farmer/Processor	Growing/harvesting	Yes	Plucking-standard: **2L1B**[25] [190] Plucking interval: **7 – 10 days** [187], [188]
Processor	Withering	Yes	Moisture content: **66 – 70%** [189]
Processor	Oxidation	Yes	Temperature: **25 ºC** [193] Duration: **(Cultivar-specific)** [190] Relative humidity: **42%** [190]
Processor	Drying	Yes	Temperature: **97 – 105 ºC** [191] Duration: **25 min. at 100 ºC** [189] Moisture content: **3%** [191]
Processor (up -/ downstream)	Grading, sorting, blending	No	

Information systems are crucial in monitoring, recording and sharing of information and play a vital role in production processes. Implementing the identified QCPs in the growing and processing steps requires reliable data collection and monitoring that fit HACCP guidelines. The following section explains tools in practice and the role of digital information systems.

Digital tools in practice

Current tools in practice can be differentiated between internal and external system. Internal system refers to data collection by a single value chain actor who is documented information during production processes. External systems refer to communication and sharing platforms

[24] Good Agricultural Practices (GAP) is a global recognised framework that addresses principles such as food safety, environment care and worker welfare.

[25] Two Leaves and a Bud (2L1B) is a plucking technique that is considered the royal standards of plucking, creates a good balance between taste properties leaf and buds, and involves plucking one young bud along with the two youngest leaves.

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that facilitates communication between supply chain actors, enabling sharing of critical (trade-related) documents such as audits, certificates, and batch-related information.

Mobile phones are a crucial communication tool among smallholder farmers, reducing reliance - thus improving efficiency - on face-to-face interactions and facilitates coordination of labour, wages and market-updates [194]. A study by Foster & Graham et al (2024), supported by field trip observations/interview during a visit to a tea processing factory in Rwanda (see Annex V – Tea Producer Rwanda), documented the use of electronic weighting (**e-weighing**) at the drop-off/collection point of freshly harvested tea leaves by workers [195]. These devices measure the weight of plucked tea leaves dropped off by workers, stores this information (date, amount, worker ID) in accounting software and prints a confirmation receipts. This information is used as a payment verification issued to the worker.

At the farm level, soil acidity and moisture content is measured using pH/moisture meters. Although these devices are relatively immobile, its use has been documented by technical

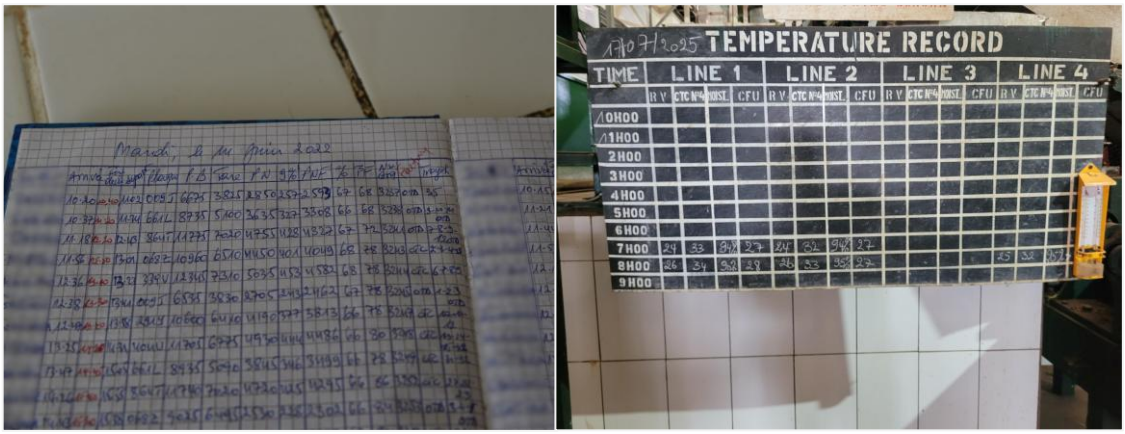


Figure 47: Recording of tea processing information, collected during fieldwork in Rwanda.

manuals such as the *Tea Growers Handbook* and *Tea Growers Guide*. These manuals produced by tea research institutes are issued to farmers and processors and offer practical guidance.

From a supply chain perspective, the use of Enterprise Resource Planning (**ERP**) systems was confirmed during an interview round with a tea processing company. However, at the time of data collection, the system – planned to be running on Microsoft Azure – was still in the process of being implemented. Current information collecting practices therefore consisted of a hybrid approach, combining analog methods, such as chalkboards and pen-and-paper records (e.g., time, temperature, humidity, batch number) which was converted to a digital form (e.g., Excel spreadsheets) (see Figure 47). Table 5 showcases potential digital tools to further optimise and automate processes in the tea value chain.

Table 6: Potential Digital Tools Tea supply chain.

Digital tool	Stage	Description
Mobile Phones	Growing/harvesting	(Increased) Communication i.e. labour, wages, market updates, resolution issues. [194]
Near Infrared Sensor (NIR)	Farming/harvesting or processing	Sorting through (chemical) compound measurements. [196]

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Internet of Things (IoT), E-nose, gas/temperature/humidity sensors	Processing (oxidation)	Measuring and real-time tracking of organic compounds temperature and humidity sensing. [197]
Artificial Intelligence (AI) & Computer Vision (CV) or Near Infrared Sensor	Sorting/grading/blending	AI combined with CV or NIR objectively supports and optimises proc. stages based on visual and chemical quality attributes. [198], [199]

Human Resource Management tasks, such as payments to workers, are carried out through a combination of Excel and payroll managing software. Communication with downstream suppliers was primarily done through mobile phones and e-mail, with the latter also used for the submission of documents and invoices. While the company does not supply tea directly to final consumers, it does sell small quantities to local supermarkets and visitors. The packages in use utilised GS1 Barcodes that were issued in Kenya. With the recent inauguration of GS1 Rwanda, locally issued product identifiers is becoming an option for (tea) producers.



Figure 48: Visualisation of Integrated Tea Trading System. (Source: EATTA - iTTS Process Flow, 2024) [200], [201]

Integrated Tea Trading System (iTTS)

The East African Tea Trade Association (EATTA) has shifted in 2020 from an open outcry auction trading system at the Mombasa Tea Auction to a digitised platform that streamlines tea trading auctions (incl. pre – and post-auction) & (electronic) transactions, titled *"Integrated Tea Trading System (iTTS)"* (see Figure 48) [200], [201]. The Mombasa Tea Auction holds a unique position in Africa's Tea industry and is considered to be a global reference point for tea pricing. Traditionally, cataloguing of the tea batches would commence by brokers through factory marks, grades and invoice numbers. Buyers would taste samples before the batch would be auctioned in an open-cry bidding. With the implementation of the iTTS at the Mombasa Tea auction, the system - developed by the Indian-based GovTech company CSM Tech - streamlines manual processes (e.g., documentation requirements, member/business

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- and catalogue management) while improving transparency through digitalisation of auction-required information flows (see

Table 7), reducing turnaround times and cost . The system also includes an e-Auction which manages (online) electronic and real time bidding by brokers and buyers.

Table 7: Sample of required information sent digitally in the iTTS from producer to warehouse prior to the auction. Source: ((EATTA), 2020)

Property Name	Property Name
Garden	The factory or producer where the tea has been produced and packaged
Invoice	Uniquely identify the batch of tea packed at the producer
Grade	Grade type of Tea e.g. BP, PF1, F1, PD, DUST1
Packages	Number of bags per invoice / batch
Packaging Type	Type of packaging e.g., bags
Net Weight	Net Weight of the batch
Tare Weight	Tare weight of each batch
…	…

The streamlining of manual tea auction processes has, according to CSM Tech, reduces overall tea trading cycle time by 40% and cost related to catalogue and managing. The iTTS example showcases the benefits of implementing digital information systems to automate and replace manual processes in agri-food systems.

4.3.4. Conclusion

Tea is a major cash crop and accounts for a large part to export-earnings and employment in (East) Africa. However, changing global market and climate conditions place growing pressure on tea producers to deliver consistent quality of tea, while complying with increasing EU requirements on food safety, certificates and ethical sourcing. The identification of Quality Control Points, following the Codex Alimentarius and HACCP principles, demonstrated the importance of quality control in harvesting and processing stages where farmers and processors interventions affect grades and auction price earnings directly. Information systems currently in use by upstream tea actors demonstrate the potential benefits of increased digitalisation in tea production and sales, ranging from potential improved tea quality following QCPs to increased transparency, reduced turnaround times and costs as demonstrated by the iTTS system in the Mombasa Tea Auction in Kenya. Increased adoption of hard – and software based-solutions aligned with internationally recognised standards will help the African Tea industry stay competitive and resilient along the ever-evolving global market and climate developments.

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4.4. Case Study III: Developing Digital Traceability Standards (GS1 Rwanda)

With the young GS1 Member Organisation (MO) in the country of Rwanda, which was inaugurated in 2024, the desire to develop a traceability solution arose in parallel. From the start it was clear that for a proposal for an interoperable traceability approach from farm to fork a solution had to be based on existing global standards. From a global perspective the core for every interoperable traceability approach is the commitment of all stakeholders to commonly accept standardised identification formats. On the identification layer of a value chain different elements come into play – entities or locations, products or items, shipping units etc. where GS1 standards enable unique identification and exact tracking (see Figure 49) [178], [202]:

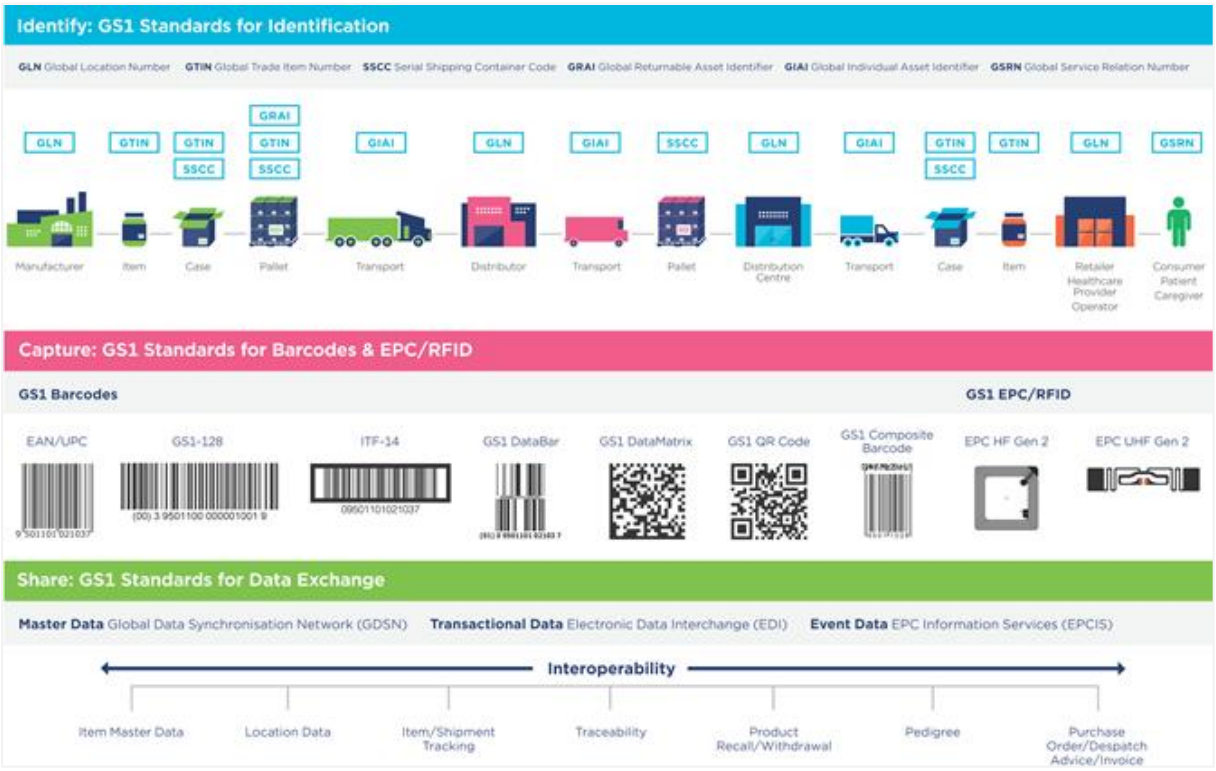


Figure 49: Overview of the value chain

GLN (entity and location level)

The Global Location Number (GLN) by GS1 of the grower is assigned to identify the grower as a value chain party as well as locations including field, farm, factory or packhouse.

The ability to uniquely identify parties and locations using GS1 standards increases product traceability and enables more accurate and precise recalls, should they occur. Usage of alternative location identification numbers may be possible, as long as it is worldwide unique and in a commonly known format, e.g. ISO. From the process actor, factory or cooperative onwards, it is recommended to use only the GLN as location identification, because it is the accepted standard in the global downstream process.

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GTIN (product class level)



A Global Trade Item Numbers (GTIN) uniquely identifies products. This information is embedded into a barcode which can also hold extended product data, such as batch/lot number, enabling to identify products, cases and pallets wherever they are in the supply chain.

GS1 standards optimise business processes, form brand loyalty and building the foundation for an efficient supply chain. The ability to uniquely identify products, cases and pallets globally also enables accurate and precise recalls.

SSCC (shipping unit level)



Global Trade Item Numbers (GTIN) and Serial Shipping Container Codes (SSCC) are used to track and identify product contents as they move from the field to the processor to shipping. Dispatch advice (or Advanced Shipping Notices, ASN) containing SSCC, GTIN and their corresponding batch/ lot numbers, and GLN are sent to customers.

GS1 standards improve visibility in product movement, provide the foundation for improved order-to-cash and will help verify the flow of goods both inbound and outbound. More efficient requirement of shipments, inventory management and shipping processes can be achieved.

Key data elements (KDE) to exchange interoperable traceability data

KDE ensure that captured and recorded data can be interpreted by all supply chain partners. KDE define the Who, What, When, Where and Why of a business process step (see Table 7). Since a lot of the KDE are expressed as identification keys, master data (MD) related to these keys will be required. The trade item class consists of its product master data, which might include the trade item's dimensions, descriptive text, nutritional information (in the case of a food product). Although master data is static, it can change over time. It is important to refer to the master data that was in effect at the time of the tracking event of concern.

Table 8: Key Data Elements

WHO	
• GLN of legal entity	Used to identify the grower or farming company that did the first sale (see sales note). Also used to identify buyers and sellers further downstream.
• Tax number	VAT number, company tax number or equivalent ID of the party.
• FBO approval number	Number used to identify a food business operator (FBO) in an official registry related to food standards and safety.
WHAT	
• GTIN	Global Trade Item Number that identifies the type of trade item.
• Batch/lot number	The batch/lot number associates a trade item with information the manufacturer considers relevant for traceability of the trade item. The data may refer to the trade item itself or to items contained in it. In combination with the GTIN the batch/lot number identifies a group of trade item instances.

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• Serial number	A code, numeric or alphanumeric, assigned to an individual instance of an entity for its lifetime. In combination with the GTIN the serial number identifies exactly one trade item instance.
• Quantity	The quantity of the respective trade item.
• Net weight	Used to identify the net weight of the trade item. Net weight excludes any packaging materials. Must be associated with a valid unit of measurement.
• SSCC	Serial Shipping Container Code that identifies an individual logistic unit.
WHERE	
• GLN of physical location	Used for location identification (Farm, Field, portion of field, etc.). Used to identify production and inventory locations.
• Name and address	Name and address of the party/location.
• Additional IDs	Identifiers used in addition to the GLN to identify the location.
WHEN	
• Date and time of Critical Tracking Event (CTE)	Timestamp marking completion of a business process step (e.g., harvesting, shipping, receiving).
WHY	
• Business process of Critical Tracking Event (CTE)	Used to record the process context of the critical tracking event. Example: Shipping.
• Disposition	Status of the traceable object subsequent to the CTE. Example: Available for sale, quarantined.
• Transaction reference	E.g. sales note, PO reference, ...

Traceability information to be shared as a grower/ farmer or producer

To ensure a stable business relation between trading partners, traceability is crucial and fosters trustworthiness. The following data set represents the minimum required and should be collected, recorded and shared (see Figure 50) [202]:

- Logistic unit identification (SSCC)
- Commodity name and, where applicable, variety name, growing method, e.g. organic
- GTIN if applicable
- Receiver identification (GLN)
- Shipping from location identification (GLN of shipping location)
- Shipping to location identification (GLN of receiving location/ trading partner)
- Shipping date
- Grower records details related to, e.g. field, seeds, details of production inputs
- Additional grower information, e.g. harvest crew, date of harvest

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- Sender identification (GLN)

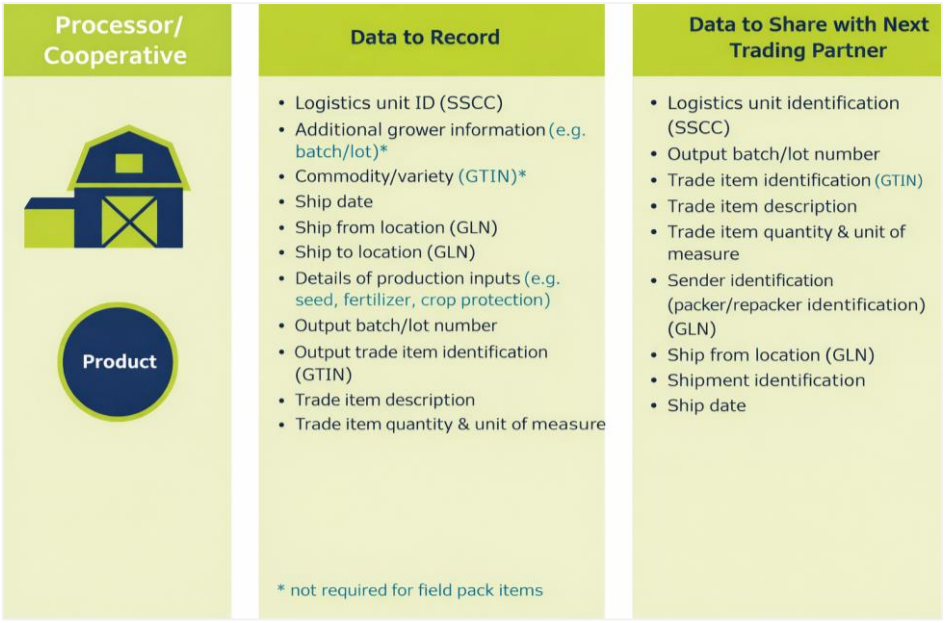


Figure 50: Processor/Cooperative Data Set

Sharing interoperable data

Using the described standards for identification, methods are paved to use the affiliated standards for data transfer, which enables interoperability between different systems or companies. There are two standards that support the GS1 traceability concept: EPCIS (2.0) for visibility event data together with the Core Business Vocabulary (CBV) and EANCOM©/ GS1 XML for transactional data like an order, dispatch advice, shipping status, receiving advice or invoice.

EPCIS

EPCIS is a significant standard from GS1 for the standardisation of data to enhance transparency and interoperability in the supply chain. The main advantages of the latest release 2.0 include support for sensor data, the use of JSON/JSON-LD and REST APIs for easier developer integration, and support of GS1 Digital Link to connect e.g. products with digital information. The standard enables the standardised capture and exchange of events such as production, shipping, or sale, to improve traceability and fraud detection. The following figure (see Figure 51) illustrates a simple business process, showing where EPCIS data may be generated [202].

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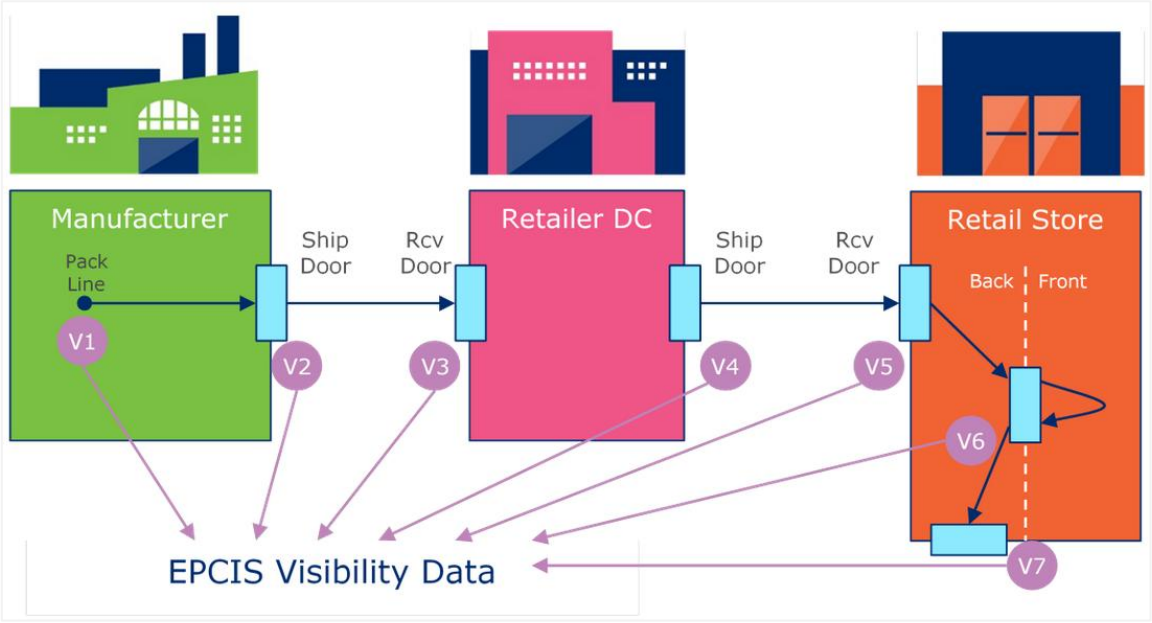


Figure 51: Simple Business Process Showing Generation of EPCIS Data

This figure illustrates a simple business process in which a trade item is manufactured, shipped to a distribution centre and later shipped to a retail store where it is received and finally moved into the sales area at the point of sale (POS). The entire business process represents a sequence of individual business steps: packaging, preparing a shipping container, shipping itself, receiving, and so on. EPCIS data provide a detailed record of each of these steps. A set of EPCIS data describing the completion of one business step is called an "EPCIS event" and a collection of EPCIS events provides a detailed picture of a business process over time and place. Taking the example of a receiving step, the information content is structured in five dimensions or KDE:

- **What** - Information about what trade items and/or shipping containers were received
- **When** - The date and time when receiving occurred, and the local time zone in effect
- **Where** - The location where the shipment was received, and where the items are expected to be following the event
- **Why** - Information about the business context, including:
    - The fact that the business step is a receiving operation (as opposed to shipping or some other business step).
    - The fact that the shipment is making normal forward progress through the supply chain (as opposed to being returned).
    - Information about who are the shipping and receiving parties, and the former and current owning parties if different than the shipper and receiver
    - Links to relevant business transaction documents, such as purchase order, an invoice, a dispatch advice (a.k.a. advance ship notice), etc.
- **How** - (New in version 2.0, optional) Captures the state of the objects using sensor information, such as temperature or humidity.

EANCOM©/ GS1 XML (optional)

GS1 EANCOM® belong to the eCom Electronic Data Interchange (EDI) standards of GS1 that integrate information sent electronically in addition to the physical flow of goods. They provide

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a ready-to-use UN/EDIFACT subset agreed between trading partners world-wide, eliminating bilateral revolving efforts with business partners. The use of GS1 keys ensures data quality, reduces errors and avoids sending redundant information in electronic messages. Any of the UN/EDIFACT components can be added to the EANCOM subset at the user's request.

4.5. Conclusion

3.	How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?
4.	What types of digital agricultural solutions are currently being used across Africa and what do case studies reveal about success, challenges and opportunities of digital tools?

Chapter 4 presented the results from the systematic literature review and three case studies on tea, cassava and GS1 Rwanda, focusing on the role of digital tools, standards and solutions on the African continent.

The systematic literature review highlighted how interest has increased since recent years, driven by continental agreements (AfCFTA, Malabo Convention etc.), Covid-19 and advancements in digital adoption. Despite steady progress on digital adoption, social and technical barriers hinder its effectiveness, with infrastructure, digital literacy and unsustainable business model preventing uptake. Key adoption drivers consist of addressing infrastructure constrains, developing user-centred digital literacy programs and solutions, and supporting these with socially embedded policy frameworks.

Cassava is a staple food in African diets and has the potential to gain even more importance in the future due to its climate-resilience properties. Nevertheless, cassava food safety is influenced by both naturally occurring compounds and environmental factors, such as lead present in the soil. Proper steps should be taken across the value chain – ranging from soil testing, controlled fermentation, soaking and packaging/storing – to minimise health risk. Specifically, farmers and processers should prioritise implementing HACCP principles during key steps in the processing of cassava to minimise risks and adhere to critical limits in the planting, fermentation, soaking, toasting, drying and packaging steps. Current EU Food Safety legislation creates barriers for cassava exporters to enter EU markets, highlighting the need for harmonised food safety standards – including digitalisation of CCP monitoring, traceability and reporting systems – to support trade.

Tea is a major cash crop and accounts for a large part to export-earnings and employment in (East) Africa. However, changing global market and climate conditions place growing pressure on tea producers to deliver consistent quality of tea, while complying with increasing EU requirements on food safety, certificates and ethical sourcing. The identification of Quality Control Points, following the Codex Alimentarius and HACCP principles, demonstrated the importance of quality control in harvesting and processing stages where farmers and processors interventions affect grades and auction price earnings directly. Digital systems, such as the iTTS at the Mombasa Tea Auction demonstrate the potential benefits of increased information system digitalisation in tea production and sales, influencing increased transparency, reduced turnaround times and costs. Adoption of hardware- and software-based solutions aligned with internationally recognised standards will help competitiveness and resilience.

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To implement a traceability solution in Rwanda that enables interoperable and independent systems, implementing existing global standards and sharing KDEs among supply chain actors arises in parallel. Specifically, implementing global recognised GS1 identification keys, including master data, GLN, GTIN, SSCC and batch/lot numbers. These interoperable traceability data standards enable common interpretation on the Who, What, When, Where and Why of business processing steps. Further interoperability integration requires adopting GS1's EPCIS (2.0) for supply chain visibility and subsequently GS1's EANCOM / XML EDI standards, allowing sharing of structured business-related information such as electronic invoices, orders information and shipping notifications alongside the physical flow of goods. These standards allow integration of various IT systems from companies and governmental agencies to communicate and share relevant information, enhancing traceability, supply chain transparency, food safety management and fraud detection.

The creation of GS1 Rwanda offers an important step to support the country's economy transition towards an open, digital inclusive trade environment by better aligning with global business standards. The local issuing of GS1 identifiers for encoding in barcodes and RFID tags helps accelerate digital integration across agricultural AVCs, improving transparency and traceability in the local AVC. By offering capacity building, technical assistance and support, the organisation can assist producers, processors, exporters and national agencies to adopt these global and interoperable standards, further strengthening and accelerating Rwanda's ability to meet international trade markets and requirements.

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5. Evolution Digital Standards Landscape

This chapter offers background information on the evolution of the digital standards landscape, providing insights in the history of the different identification methods and its applicability into ensuring transparent, efficient and accountability throughout the supply chain. The following section explores the role of digital standards for the African Union and how the AU member states can utilise a leapfrog strategy to incorporate modern standards into their agricultural businesses. It draws insights from desk research. This chapter answers the following research questions:

4.	How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?

Chapter 5 explored the history of the digital standards landscape, highlighting how the Global Standards 1 developed over the past 50 years, offering improved traceability, transparency and interoperable benefits in agri-food value chains. Consecutively, it showed how African member states can adopt a pragmatic leapfrog approach by adopting and promoting modern, open-source, future-proof and interoperable digital standards, supported by targeted policies that incentives and promote capacity-building. This enables improved SME inclusion, trade readiness and alignment with future global and sustainability requirements.

5.1. History of Digital Landscape Standards supporting Agricultural Trade

The "farm to fork" supply chain is the entire food production process, from growing crops or raising animals on a farm to the final consumption of the food by a consumer. This process includes production, handling, processing, packaging, and distribution through wholesalers and retailers to the end consumer.

The GS1 system – with its background of more than 50 years and being accepted in every country of the world – can be used to generate cross-industry unique identification keys for almost all objects and actors across the supply chain network. This allows a wide variety of objects such as products, locations, companies, assets, or transactions to be identified. GS1 identification keys allow companies to efficiently access information about goods in their supply chains and share this information with trading partners. The fact that GS1 identification keys are globally unique ensures that the information about the objects they represent can be shared between organisations and therefore increases supply chain visibility and stability for trading partners. All GS1 keys are unique (within the GS1 coding scheme), non-significant, and international (GS1 identification keys may be used in all countries and all sectors).

Global standards, starting in the food industry, were established in 1973 (see Figure 52) by the predecessors of GS1 [202].

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Figure 52: History of GS1-Standards

In 1973, the leaders of the US retail industry agreed on the barcode, and in 1974 the first scan of a pack of Wrigley's took place in a supermarket in Ohio. Industry leaders came together to change the way we shop and created the barcode. From that moment on, a simple scan at the checkout linked a physical product with its digital identity – and with information that could be shared along the entire supply chain and with consumers. Information about products from the agricultural industry (i.e., corn, meat, fish, flowers), chemical industry, or government institutions can be labelled with these identifiers. Figure 53 illustrates the composition of the GTIN-13 identification number and the meaning of each segment [202].

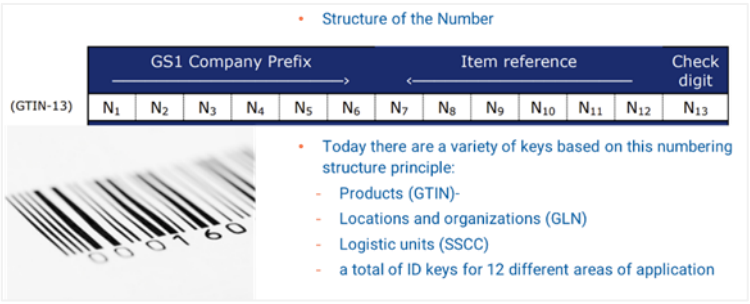


Figure 53: The Identification Number

2D Codes powered by GS1 are starting to transform the simple scan, opening a gateway of in-depth product information. From an in-store scanner or mobile phone, QR Codes powered by GS1 will create new opportunities to improve business operations, consumer experience, patient safety and sustainability initiatives (see Figure 54) [202].

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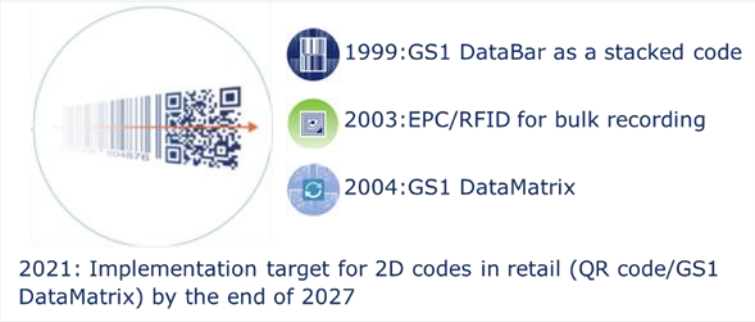


Figure 54: Further development of automatic data collection

Traditional barcodes are expanded and be used beyond checkout counters for wholesale multi-packs, cases, and cartons. In 1989, GS1 published its first international standard for electronic data interchange (EDI), creating an efficient, secure, and automated way for trading partners to seamlessly exchange information and communicate with one another (see Figure 54 and Figure 55) [202].



Figure 55: Further development of data exchange

The identification standards are used in logistics applications on several different levels, e.g. multipack, carton, pallet. A notable expansion into healthcare has taken place, and in 2006 the GS1 Traceability Standard was developed. The GS1 architecture is a unified system managed by GS1 experts that develops and implements standards for cross-company business processes worldwide within the scope of identify, capture, share. The GS1 identification standards uniquely identify products, locations, and other business-related entities. The GS1 data capture standards make the identification numbers readable via barcodes and RFID. The GS1 standards for information exchange enable the sharing of data with trading partners and consumers.

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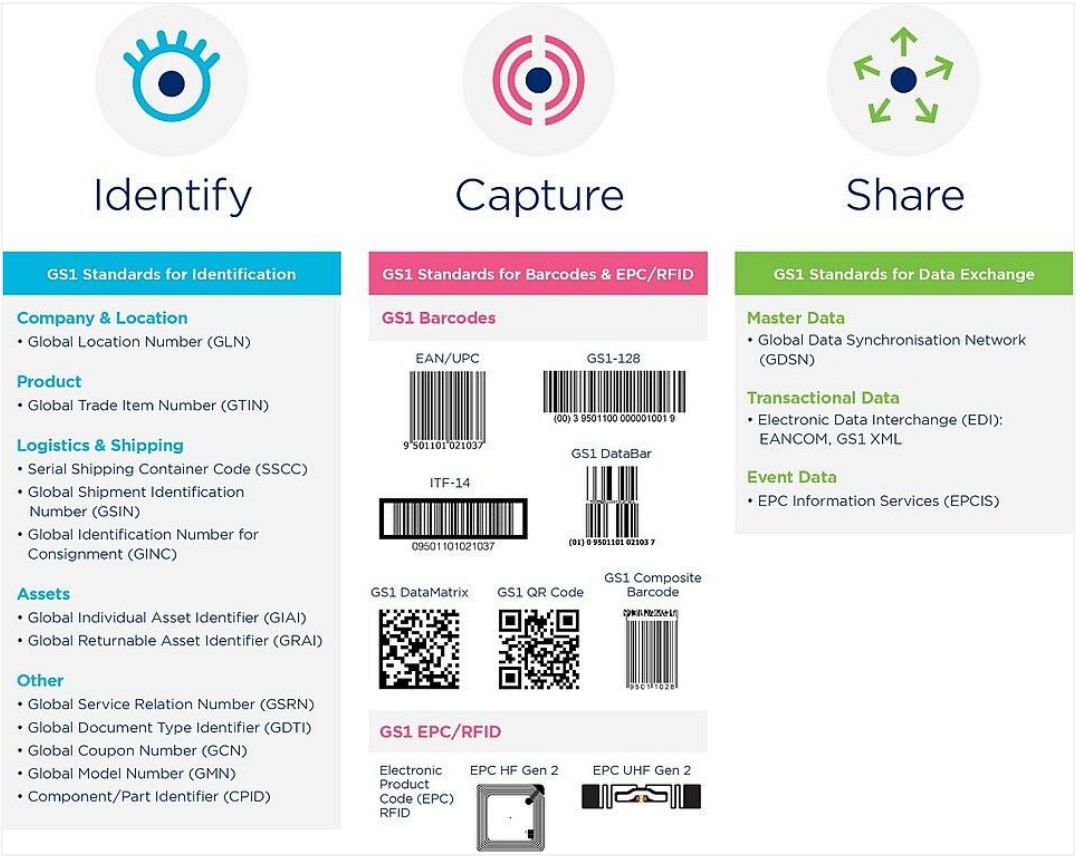


Figure 56: GS1 Architecture

GS1 standards are essential for traceability and for sustainable processes. Traceability includes the tracking the food's journey from farm to fork and thus is vital for their transparency allowing consumers to know the origin of their food, the processers involved, and the inputs used (see Figure 57) [202].

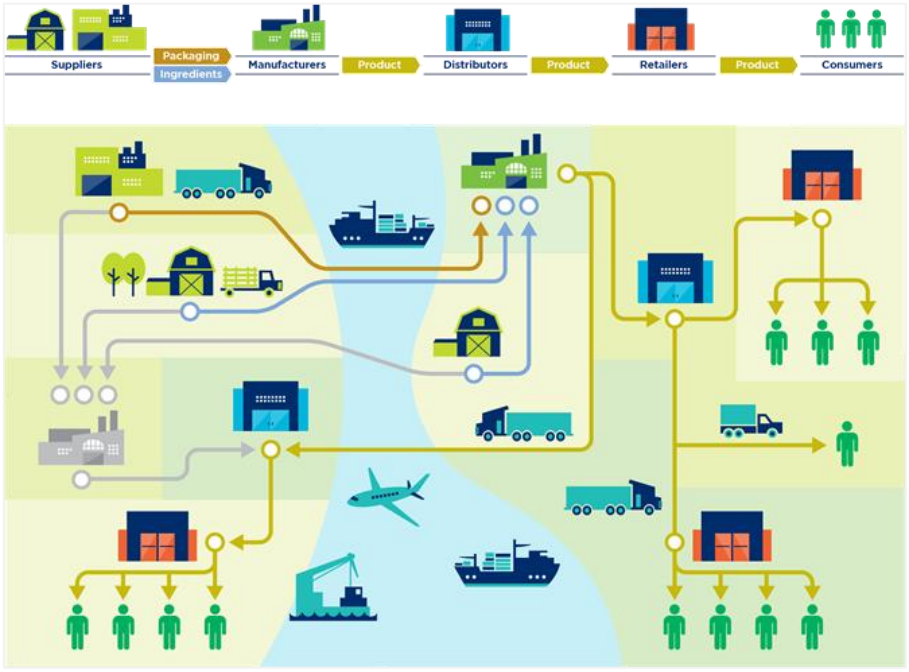


Figure 57: Role of Traceability in global value chains

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Sustainability: The "farm to fork" concept is central to strategies that aim at creating more sustainable, healthy, and environmentally friendly food systems by minimising waste, reducing greenhouse gas emissions, and preserving biodiversity. GS1 has analysed and identified its set of key sustainability priorities as follow (see Figure 58) [202].



Figure 58: Key Sustainability Priorities GS1

These priorities address the growing need for transparency, efficiency, and accountability throughout the value chain.

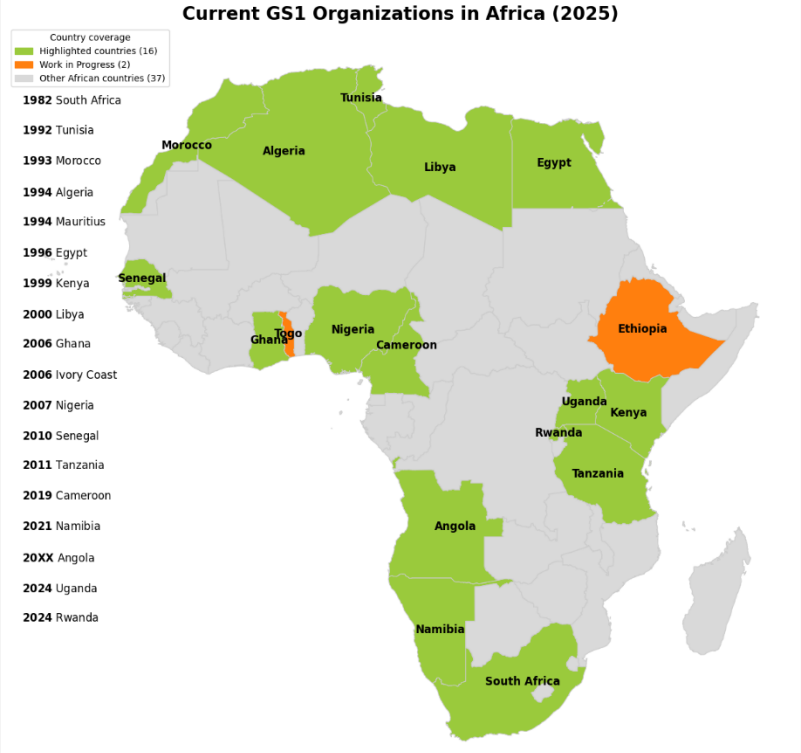


Figure 59: Current GS1 Organizations in Africa (2025) – own illustration

Figure 59 shows the establishment of GS1 as Member Organisation in the different countries in Africa. There are five GS1 member countries in STREAMING: Kenya, Rwanda, Senegal, South Africa and Tunisia. In the two countries of Ethiopia and Togo, being represented in STREAMING by institutions, GS1 is not yet established (see map above).

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5.2. Future Outlook of the AU Digital Landscape

5.2.1. Pragmatic Leapfrog Strategy for AU Member States

As outlined in the previous chapter, numerous business standards have emerged over recent decades. Some remain essential; others are in decline; several – though still common – rely on outdated technologies. At the same time, modern standards are gaining adoption. For regulators, trade associations, solution providers, and user companies across AU (African Union) member states, the central question is: ***Which standards should we endorse and prioritise?***

A pragmatic, forward-looking approach – leapfrogging legacy where feasible – can reduce costs, accelerate scalability, and align with contemporary skills.

Why prioritisation matters: Supporting the full catalogue of standards introduced since the 1970s is neither economical nor strategic:

1. **Cost:** Adding support for every legacy and niche standard is prohibitively expensive.
2. **Scalability and time-to-market:** Excessive compatibility burdens slow delivery and hinder scaling.
3. **Workforce skills:** Today's graduates are trained on modern technologies (e.g., JSON and REST APIs) rather than legacy ones (e.g., XML and SOAP).

Implication: Policy recommendations should adopt a consistently pragmatic, forward-looking stance – i.e. endorsing standards that are likely to remain relevant, are state-of-the-art, and are straightforward to adopt. So, rather than mirroring implementations from other parts of the world, African states could **leapfrog**: selectively promote a focused set of modern, interoperable standards with clear long-term viability and strong ecosystem support.

In inter-organisational data exchange, it is vital to look beyond a narrow, internal enterprise view when considering standardisation. A broader, ecosystem-wide approach is needed – one that reflects existing digital infrastructures, sector-specific needs, regulatory requirements, and global technological trends. Only through thorough, evidence-based analysis of this wider context can stakeholders make informed choices about adopting a coherent and future-ready set of identification, data capture and data sharing standards.

This approach embeds interoperability, scalability, and long-term sustainability from the outset, laying the groundwork for a resilient and inclusive digital transformation.

Illustrative examples:

1. *Next generation product identification:* For more than fifty years, retail point-of-sale (POS) relied on the EAN/UPC barcode. As of 2028, POS scanners are expected to also support 2D symbols, e.g., QR Codes powered by GS1. The latter encodes GS1 Digital Link URIs, embedding the trade item identifier (GTIN) as a web address and therefore enabling consumer engagement and connecting to related data and services (see Figure 60).

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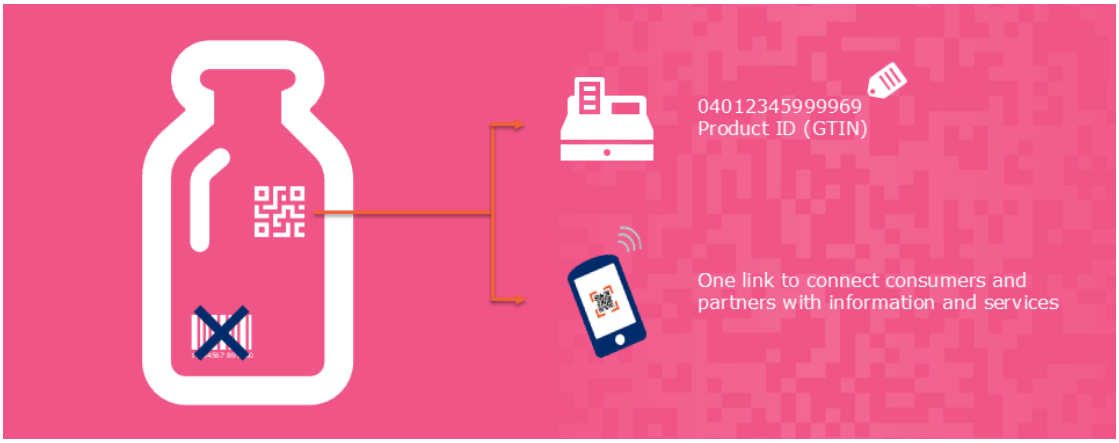


Figure 60: Benefits of applying QR Codes Powered by GS1

Thus, retailers across Africa should be encouraged – starting now – to procure POS systems that read both EAN/UPC and 2D codes. This dual capability unlocks near-term compatibility and long-term innovation. Based on this, suppliers can connect products to online information and services, opening additional business opportunities across the value chain.

2. *Modern technology stack for data sharing:* Sharing e.g. master and traceability data is a critical enabler across multiple applications, particularly within the agricultural sector. Master data is pivotal for operational efficiency, collaboration and fast time-to-market. Traceability data has become indispensable as retailers increasingly require suppliers to specify the origin of individual product batches – driven by the need to enhance food safety, foster consumer trust, and comply with evolving regulatory frameworks.

   Table 9 highlights key aspects of state-of-the-art approaches to data sharing.

Table 9: Current Best Practices for Effective Data Sharing

#	Approach (if applicable/where possible) *	Why This Is Beneficial
1	Apply globally unique, resolvable IDs (e.g., GS1 Digital Link URIs)	▪ Reduces mapping overhead ▪ Avoids vendor lock-in ▪ Simplifies IT integration
2	Use harmonised, globally recognised data models and vocabularies (e.g., GS1 Web Vocabulary)	▪ Improves validation and searchability ▪ Enables automated quality checks ▪ Ensures clear data interpretation
3	Consider API-first approach (e.g. for accessing visibility event data)	▪ Reduces manual processes and cost ▪ Eliminates media discontinuity ▪ Enables faster, real-time data access
4	Use JSON/JSON-LD	▪ Is developer-friendly (e.g. as it is easy to extend, read, and integrate) ▪ Empowers machine interpretability
* Organisations must recognise that the effective use of any technology depends on the existence of a global application standard – an agreed framework that ensures industry-wide consistency in implementation. A recent example is GS1's provisional EUDR Application Standard, which also specifies a lightweight JSON/JSON-LD notification format based on the GS1 Web Vocabulary. The mechanism aligns fully with the approaches outlined in this table. However, such an option is not yet available for many other use cases.		

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5.2.2. African organisations to use and engage in Open-Source

Digitisation is no longer optional for businesses seeking competitiveness and resilience in global markets. Open-source initiatives might be a *promising building block to provide access to high-quality software, foster innovation, and reduce dependency* on proprietary vendors.

Why open-source matters: Assuming that a given open-source project is published under an appropriate licence (i.e. specifically allows commercial use without noteworthy constraint), it comes with several tangible benefits:

1. **Cost Efficiency:** Eliminates expensive licensing fees, thereby reducing total cost of ownership.
2. **Vendor Independence:** Avoids lock-in to proprietary ecosystems, enabling flexibility and bargaining power.
3. **Local Adaptation**: Enables customisation for specific linguistic or operational needs (e.g. via requirements submissions or source code suggestions).

Implication: Policy recommendations should consider promoting open-source adoption through incentives, procurement policies, training programs, partnerships with universities and tech hubs, engaging local IT service providers, joining open-source consortia/initiatives, and alike.

Illustrative examples: see Table 10 (please note: this list is not exhaustive and does not constitute an endorsement of any specific software mentioned).

Table 10: Selected open-source initiatives

#	Open-Source Initiative	Description	More Information
1	*ERPNext*	ERP system for small and medium-sized businesses	https://frappe.io/erpnext/
2	*Mifos X*	Core banking platform designed for microfinance and financial inclusion	https://mifos.org/
3	*Medusa*	E-Commerce platform	https://medusajs.com/
4	*LibreOffice*	Alternative office suite, including Writer, Calc, Impress, and more	https://www.libreoffice.org/
5	*GS1 support for data capture and exchange*	Tools and software libraries for barcode generation, RFID data translation, etc.	https://github.com/gs1/
6	*OpenEPCIS*	fully compliant implementation of the GS1 EPCIS standard for supply chain visibility	https://openepcis.io/
7	*Linux*	Open-source operating system that supports various distros	https://www.linux.org/
8	*Pkgsr / Nix*	Offers free solutions for creating replaceable systems and environments for mass deployment	https://www.pkgsrc.org/ https://nixos.org/

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5.3. Conclusion

4.	How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?

Chapter 5 offers background information on the evolution of the digital standards landscape, providing insights in the history of how identification methods, such as GS1, ensured transparent, efficient and accountability throughout the supply chain. The development of the GS1 standards over the last 50 years has improved efficiency and interoperability among trade partners and is a foundation step to ensure visibility within the agricultural chain through its identify - capture - share elements. Recent initiatives of adopting GS1 Standards among African member states showcases the ongoing developments to align their domestic economies with internationally accepted standards, improving both efficiency and improving trade-readiness.

Looking forward, African member states have the potential to adopt a pragmatic, forward-looking leapfrogging approach, focusing on strong modern, interoperable ecosystems. In addition, open-source solutions and digital tools can enable key actors in African countries, such as SMEs and smallholder famers, to access and adopt global-recognised standards benefitting from cost efficiency, vendor independence and local adaptation while aligning with future (sustainability) regulations and future trade opportunities. In promoting such approach, policies should provide incentives, procurement and training programs to form partnerships with academia, tech hubs and local IT providers to endorse standards that are likely to remain relevant. African states should selectively promote a set of modern standards with long term viability – and ecosystem support, reflecting existing digital infrastructure, sector-specific needs, regulatory environment and following global technological trends.

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6. Gaps and Future Opportunities

Chapter 6 presents an expanded and refined first-draft analysis of the key gaps, challenges, and preliminary recommendations for digitalisation in agrifood value chains across African partner countries. It draws insights from desk research, findings from a conducted survey and Trade & Digitalisation datasets. Specifically, chapter 1-5, academic scholarship on economic embeddedness and governance [39], [41], [44], ethnographic insights into hybrid and informal trade systems [42], [203], [204], empirical data from the STREAMING Survey (2025), practitioner knowledge and selected World Bank datasets. This chapter answers the following questions:

5.	What are the current gaps between the current state of digital solutions and the ideal future state required under AfCFTA and Africa-EU trade aspirations?
6.	Which opportunities are arising from agricultural transformation to strengthen and accelerate agricultural production, quality assurances, transparency and market access?
7.	What actions, policies and continental strategies are needed to accelerate trade digitalisation and digital innovation to enhance cross-border interoperability and support smallholder farmers and SMEs?

Chapter 6 highlights how digitalisation in African agri-food chains offer significant opportunities beyond technical efficiencies, including improved coordination, stabilised information flows and reduced uncertainty. Inclusivity and market participation are improved, especially for smallholders and women. However, the current fragmented digital landscape, limited infrastructure and low digital literacy skills limit uptake, requiring targeted context-sensitive policies that prioritise capacity building and alignment with global standards to unlock the full potential of digital transformation.

6.1. Key Gaps and Challenges in Africa's Agricultural Sector

The tone and analytical depth have been aligned with the ethnographically grounded style of Chapter 2.5.2, emphasising the social embeddedness of economic practices, the coexistence of formal and informal systems, and the lived realities of actors within agricultural markets.

Important methodological note: International datasets, grey literature, surveys and academic literature are often available only for selected countries or sub-regions. As such, the insights presented here should not be read as continent-wide generalisations. This limitation is inherent to current data availability and will be reduced as STREAMING expands its empirical evidence base, especially through fieldwork and co-creation processes in WP3 and WP5.

6.1.1. Key Gaps and Challenges

1. Socio-economic and trust-related barriers

Digitalisation unfolds within economic and social landscapes shaped by long-standing norms of reciprocity, trust, and negotiated cooperation – elements characteristic of socially embedded markets (Polanyi 1957; Schmitz 2018). In many agrifood chains, mistrust towards digital systems arises not from technophobia, but from the fear that such tools may function as mechanisms of surveillance or administrative control. World Bank Global Findex data show that agricultural income in Sub-Saharan Africa continues to be paid predominantly in cash, including payments received by approximately 66 million women. This reliance on cash reflects

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not merely infrastructural gaps but a deeper orientation towards interpersonal trust and the perceived security of face-to-face transactions.

2. Limited digital literacy and inaccessible training

Digital literacy is unevenly distributed and strongly dependent on exposure, language, education, and social networks. Training formats often fail to align with everyday working rhythms, mobility constraints, and the practical realities of agricultural labour. Findings from the STREAMING Survey (2025) underscore that online-only training excludes the majority of intended users. World Bank analyses similarly highlight that digital transformation succeeds only when training is contextual, practice-oriented, and grounded in the lived experience of farmers and traders.

3. Infrastructure constraints and lack of affordable devices

Electricity, connectivity, and device access remain foundational barriers to digital participation. Many rural actors cannot afford or maintain smartphones, tablets, or scanning equipment. These gaps limit the practical uptake of even well-designed digital standards. World Bank guidance on digital agriculture stresses that without reliable infrastructure, digital systems remain aspirational rather than operational.

4. Fragmented digital ecosystems

Across partner countries, numerous digital platforms, registries, and agritech tools operate in parallel, yet lack coordination, interoperability, and visibility. This fragmentation creates information asymmetries and contributes to user fatigue. World Bank insights from West African digital platforms reveal comparable patterns, suggesting that fragmentation is a structural rather than country-specific phenomenon.

5. Misalignment between standards and local practices

Standards often reflect regulatory and cultural assumptions from outside the region. Food safety, quality assessment, and handling practices vary considerably across African markets. Imported standards may misfit these local realities, leading to work around practices or selective adoption. Interoperability between national systems remains limited, further complicating cross-border trade.

6. Gendered digital divides

Despite their central roles in aggregation, processing, and trade, women frequently face lower digital literacy, reduced device access, and fewer financial tools. World Bank data show that most agricultural payments to women remain exclusively cash-based, limiting their engagement with digital platforms that require mobile-money or banking infrastructure. Without targeted interventions, digitalisation risks reinforcing existing gendered inequalities.

7. Governance gaps and weak institutional coordination

Digital governance frameworks often lack clear mandates, coordination structures, and sustained resourcing. Informal and community-based governance systems – central to enabling infrastructure, maintaining stability and mediating economic relations – remain insufficiently integrated into digitalisation strategies. World Bank recommendations emphasise

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the importance of ministerial coordination units to centralise knowledge, map initiatives, and strengthen governance capacity.

6.1.2. Preliminary Recommendations

1. Strengthen communication and advocacy

Digitalisation must be communicated not as a form of surveillance but as a mechanism that supports economic agency, reduces risk, and expands market access. Messaging should be channelled through trusted intermediaries - market leaders, pitchmen, cooperatives, women's groups - and grounded in everyday economic logic. Framing digital adoption in terms of concrete benefits (e.g., improved prices, reduced spoilage, reliable buyers) is essential to building acceptance.

2. Develop inclusive, context-sensitive training systems

Training should be free, easy to access, local, multilingual, and embedded in the spaces where economic life takes place - markets, warehouses, cooperatives, aggregation points, and remote farming communities. Trainers with farming or trading backgrounds ensure cultural and practical relevance. Peer-to-peer learning models and accessible demonstration formats enhance adoption and knowledge retention. These findings are strongly supported by the STREAMING Survey (2025) and by World Bank analyses on digital agriculture capacity building.

3. Improve access to infrastructure and devices

Reliable electricity and rural connectivity are prerequisites for any meaningful digitalisation. Subsidised or community-owned devices - shared smartphones, tablets, or market-based digital kiosks - can lower costs for vulnerable groups. Digital tools should be lightweight, low-bandwidth, and offer offline functionality in case of limited internet access, in line with global guidance for digital agriculture ecosystems.

4. Design systems aligned with local economic logics

Digital systems must be conceived as complementary to existing practices rather than as replacements. Allowing cash-based transactions, focusing on tracing goods rather than individuals, and ensuring intuitive interfaces increases trust and reduces friction. Alignment with social and economic routines enhances adoption, particularly in informal or hybrid markets.

5. Co-develop adaptive and culturally grounded standards

Standards should be developed collaboratively with farmers, traders, aggregators, processors, and local authorities. Co-creation ensures relevance, legitimacy, and higher adoption rates. Food safety and quality norms should be adapted to local practices while maintaining pathways towards regional harmonisation. Start with checking existing initiatives and practices elsewhere, drawing on experiences from others.

6. Strengthen coordination and knowledge management

Ministries and public institutions require dedicated coordination mechanisms to map, evaluate, and integrate digital initiatives. Communicating de-centralised repositories of tools, standards,

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and ongoing projects reduce duplication and improve policy coherence – while guaranteeing responsibility and trust of origin. To remain effective in these coordination efforts, dynamic and adaptive policy frameworks that create institutional space for flexible and data-driven policies allow ministries and policy makers to stay in line with the rapidly evolving digital ecosystem. Local coordinators - cooperative managers, market leaders, women's associations, digital champions - can support day-to-day implementation and capacity transfer.

7. Build responsive feedback and grievance systems

Accessible and user-centred feedback channels ('wishes and complaints systems') create transparency, strengthen trust, and reinforce accountability. Moderators or coordinators may be able to foster communication between stakeholders and serve as ombudspeople. These mechanisms should be institutionalised rather than treated as add-ons, enabling continuous system improvement.

6.2. Opportunities Emerging from Digital Transformation

Digital transformation in African agrifood systems opens a range of opportunities that extend well beyond technological efficiency. In line with the analytical tone of previous chapters, these opportunities must be understood as emerging within socially embedded, sustainability driven, hybrid economic systems rather than purely formal structures. Evidence from the Digital Landscape Report, the STREAMING Survey (2025), World Bank datasets and ethnographic insights indicate that even low-threshold digital tools - such as smartphones (with a certain graphical user interface), WhatsApp communication channels, or simple product or packages identification systems such as barcode readers - can improve coordination, stabilise information flows and reduce uncertainty across fragmented value chains.

Digital tools offer the possibility to broaden market participation by connecting smallholders and traders - including those operating in informal or semi-formal settings - to new buyers, price information and logistical networks. Improved transparency can contribute to reduced post-harvest loss, better risk management, efficient logistics and increased predictability in trade relations. Importantly, digitalisation carries strong potential for women's economic empowerment. When designed in accessible, multilingual and context-appropriate formats, digital systems can strengthen women's bargaining power, expand access to financial services and foster new forms of collective organisation.

Furthermore, digitalisation can accelerate regional and continental market integration. Interoperable, multi-lingual and adaptive systems create pathways toward gradual harmonisation of standards and documentation, supporting ambitions articulated in Agenda 2063 and the African Continental Free Trade Area (AfCFTA). In this sense, digital transformation represents an opportunity to make agrifood systems more inclusive, efficient and interconnected - provided that solutions remain affordable, culturally coherent and aligned with the lived realities of farmers and traders.

6.3. Aligning Opportunities AU's Agenda 2063 ambitions

The African Union's Agenda 2063 outlines a transformative vision for "The Africa We Want", centred on inclusive growth, sustainable development, regional integration, technological

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advancement and people-driven prosperity. The digitalisation of agrifood value chains intersects directly with several of Agenda 2063's aspirations, including economic empowerment and guaranteed food security and nutrition (Aspiration 1), continental market integration (Aspiration 2), technological and scientific innovation, and gender-responsive development (Aspiration 6).

Findings from this Digital Landscape Report, the STREAMING Survey (2025), World Bank datasets, and ethnographic work on informal market systems show that digitalisation has significant potential to advance these goals. Enhanced traceability, improved information flows, strengthened quality assurance, and more reliable market access contribute to Agenda 2063's ambition of transforming African agriculture from predominantly raw commodity production into a value-adding, competitive and integrated sector. Digital tools can accelerate formal trade flows, support the African Continental Free Trade Area (AfCFTA), and broaden participation in cross-border markets. Gender-sensitive digital interventions, particularly those designed for women smallholders and traders, reinforce the Agenda's commitment to inclusive and people-centred development which also emphasises the informal part of the agricultural sector.

At the same time, achieving alignment requires a carefully balanced approach not only between market stakeholders but also with authorities. Much of the continent's agrifood economy continues to rely on informal and hybrid systems - economies shaped by trust, reciprocity, and negotiated cooperation, as described by Polanyi (1957), Mauss (1925), Scott (1998), and recent ethnographic research on West African markets [39], [41], [204]. The STREAMING Survey and World Bank Global Findex data confirm that a large share of agricultural income in Sub-Saharan Africa, including payments to approximately 66 million women, remains cash based. These dynamics reflect not only structural constraints but also the embeddedness of economic practices in local social relations.

A rigid or accelerated formalisation agenda risks excluding precisely those actors who sustain the agrifood system. Digital systems that require formal registration, constant connectivity, detailed data entry or strict compliance with externally defined standards may be inaccessible for smallholders, informal traders and women. This would undermine Agenda 2063's objectives by reinforcing inequalities rather than reducing them.

Therefore, aligning digital innovation with Agenda 2063 requires flexible, inclusive and context-sensitive strategies. Digital systems should be designed to accommodate informality rather than override it - supporting incremental steps toward formalisation while safeguarding the adaptive, socially regulated practices that underpin many markets. Traceability systems might focus on product flows and aggregator networks, rather than individual-level identification. Platforms should allow optional certification pathways and hybrid (e.g., analog-digital) documentation practices. Training and capacity-building must be locally grounded, multilingual, affordable and accessible, particularly for women and rural communities. Thinking within generations of people, one has to keep progress and adaptability of young and older users in mind – also to adjust trainings to altered conditions.

In summary, the opportunities identified in the digital landscape offer strong entry points for advancing the ambitions of Agenda 2063. But alignment must be rooted in the realities of African agrifood systems and their societies. Inclusive, co-created digital tools - tested through STREAMING's piloting and stakeholder engagement processes - can contribute significantly

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to the continent's long-term transformation without disrupting the social and economic systems that millions depend on.

6.4. Implication Development and Trade

The synthesis of the Digital Landscape Report, Agenda 2063, ethnographic insights into informal market systems and STREAMING data reveals important implications for development and trade for intra-AU and to the EU. Digitalisation holds the potential to significantly strengthen regional and continental integration by enhancing visibility, traceability and quality assurance throughout agrifood value chains. These improvements can reduce transaction risks, increase investor confidence, improve efficiency and generate economic advantages, supporting African economies in shifting from fragmented local markets to more structured, higher-value regional trade. Such processes align closely with the long-term development aspirations articulated in Agenda 2063.

Yet, the implications of digitalisation are not uniformly positive. A central insight emerging from both qualitative and quantitative evidence is that informal and semi-formal economies - where a large proportion of agricultural trade takes place - are highly adaptive, socially regulated and essential to local livelihoods. Rapid or rigid formalisation risks excluding vulnerable actors, particularly women and small-scale traders, who may lack the resources or institutional access required to comply with formal digital systems. Such exclusion would directly contradict the people-centred and inclusive development vision of Agenda 2063.

Consequently, digitalisation strategies must be designed to bridge both formal and informal trade practices rather than replace one with the other. Systems that accommodate hybrid documentation, offer offline functionality, allow cash-based or easily accessible digital (e.g., mobile money) transactions and integrate community-based governance mechanisms are more likely to be adopted and to generate developmental benefits. When approached in an inclusive and context-sensitive manner, digitalisation can enhance development outcomes, while also enabling trade integration, acting as a catalyst for structural transformation while safeguarding the social and economic systems on which millions depend.

6.5 Conclusion

5.	What are the current gaps between the current state of digital solutions and the ideal future state required under AfCFTA and Africa-EU trade aspirations?
6.	Which opportunities are arising from agricultural transformation to strengthen and accelerate agricultural production, quality assurances, transparency and market access?
7.	What actions, policies and continental strategies are needed to accelerate trade digitalisation and digital innovation to enhance cross-border interoperability and support smallholder farmers and SMEs?

Chapter 6 presented a first-draft analysis of the key gaps, challenges, and preliminary recommendations for digitalisation in agrifood value chains across African partner countries and draws insights from multiple sources, including previous chapters, STREAMING survey (2025) and ethnographical insights and additional relevant material. Digital transformation in African agrifood systems is more than a technical transformation, it offers structural opportunities to bring socio-technical change, creating agri-food systems that are more

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efficient, inclusive and interconnected. Despite the potential, several gaps in digital solutions and trade digitalisation create obstacles to fully realise the AfCFTA, Agenda 2063 and Africa-EU trade aspirations. Current digital tools and ecosystems remain fragmented, misaligned with local realities, limited by infrastructure and suffer from limited digital literacy and trust & legitimacy barriers.

At the same time, evidence from the Digital Landscape Report, the STREAMING Survey (2025), World Bank datasets and ethnographic research shows that even low-threshold digital tools can stabilise information flows, reduce uncertainty and broaden market participation across fragmented value chains, offering yield, quality assurance and traceability improvements. As a result of improved market linkages and digitalisation, smallholder farmers, traders and processors benefit from improved risk management, reduced post-harvest losses and inclusion, especially for women and vulnerable groups.

To accelerate digital trade, digitalisation and support local smallholders and SMEs, policies and strategies must promote inclusive and context-sensitive training systems that are aligned with local cultural, social and economic realities. This enables African member states to improve digital trade-readiness, international competitiveness and meet future global and sustainability requirements.

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7. Moving Forward

This final chapter synthesises the analytical and empirical findings from chapter 2 – 6, outlining a comprehensive five-page framework for guiding digital agricultural transformation - as well for value chain and institutional stakeholders, authorities and IT providers. The analysis adopts a hybrid scientific–policy style intended to be analytically robust and evaluator-friendly. It draws insights from earlier chapters, desk research, surveys and Policy & Regulatory Frameworks. Specifically, it integrates findings from Chapters 2–6 of this Digital Landscape Report, ethnographic insights into informal and hybrid economies [39], [42], [44], [203], [204], evidence from the STREAMING Survey (2025), World Bank datasets, and the continental ambitions outlined in Agenda 2063. This chapter addresses the main research question as well as the following:

7.	What actions, policies and continental strategies are needed to accelerate trade digitalisation and digital innovation to enhance cross-border interoperability and support smallholder farmers and SMEs?

Chapter 7 highlights how digital transformation reshapes socio-economic landscape and institutional frameworks across African agrifood systems. When combined with robust infrastructure improvements, inclusive training ecosystems and context-sensitive policies, digitalisation has the potential to accelerate the goals of Agenda 2063, strengthen regional integration and improving livelihoods and resilience across the continent.

7.1. Pathway to Digital Agricultural Transformation and recommendations

Digital agricultural transformation in African agrifood systems is not merely a technological process but a profound socio-economic and institutional transition.

A. Transforming agrifood systems within complex socio-economic contexts

Chapter 2 of the Digital Landscape Report highlights that African agrifood systems are undergoing structural transformation under the pressure of climate shocks, demographic expansion, fluctuating global food demands and persistent market fragmentation. Despite strong entrepreneurial activity, value chains remain highly segmented, with smallholders, aggregators, traders, processors and exporters often operating in parallel worlds with limited coordination. Digitalisation offers mechanisms for reducing information asymmetries, improving predictability and creating pathways to higher-value markets. However, ethnographic research demonstrates that agricultural actors operate within highly socialised economies shaped by trust, reciprocity and moral expectations rather than bureaucratic formality. This means that digital systems must not destabilise the very social infrastructures that hold markets together.

B. Aligning digitalisation with continental and national policy ambitions

Chapter 2 shows that Africa's political architecture for digitalisation is ambitious. Agenda 2063, the African Union Digital Transformation Strategy, DE4A and CAADP provide strong frameworks for digital agriculture. Several countries have established national digital strategies, ICT masterplans and agricultural data policies. Yet these frameworks frequently

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struggle to translate into practical implementation. Ministries often lack cross-institutional coordination, and agricultural, digital and trade institutions operate in policy silos. As a result, digital agriculture initiatives remain fragmented, dependent on donor funding or standalone profit-driven business models and insufficiently aligned with national development planning. A transformation pathway – for each and every country or region – must therefore build on local basis, explicitly embed digitalisation in policy processes, create coordination units and build sustainable domestic expertise.

C. A fragmented digital ecosystem with limited sustainability

Chapter 3 identifies that Africa hosts hundreds of digital agriculture tools, including digital extension services, e-market platforms, satellite-based advisory systems, IoT monitoring tools, logistics applications and traceability solutions. The mapping reveals that many tools fail to reach scale due to limited digital literacy, low farmer trust, device unaffordability, electricity shortages, negative vendor lock-in effects and lack of long-term business models. The STREAMING Survey confirms that digital tools are often experienced as complex, costly or mismatched to real-world needs. World Bank research reinforces this, noting that digital agriculture can only scale when systems are designed for low connectivity, low literacy and variable socio-economic contexts. The transformation pathway therefore requires a strategic shift from donor-driven pilots toward sustainable, locally relevant and globally interoperable systems.

D. Standards and data infrastructures as pillars of transformation

Chapter 4 emphasises that standards are essential for enabling market access, food safety, interoperability and regional integration. Yet GS1 adoption is uneven, digital identifiers of partners and products remain scarce, and many businesses still rely on handwritten logs. Certification systems are costly and documentation formats vary across product categories or countries and regions – often driven by market power. Rigid or externally imposed standards risk excluding informal actors who form the backbone of Africa's agrifood economy. The transformation pathway thus requires adaptive, tiered standards that allow smallholders, traders and processors to participate in digital systems even on global scale without needing full formalization at the outset.

Pathway to digital agricultural transformation

Synthesising insights from the Digital Landscape Report and complementary empirical evidence reveals six interdependent pillars for a viable transformation pathway.

1. Building foundational enablers

Digital agriculture cannot function without adequate infrastructure and IT providers. Electricity reliability, device affordability and rural connectivity remain the most significant structural constraints. Investments should prioritise shared community resources such as digital kiosks in markets, solar-powered charging hubs and community-owned devices. Offline-first system design ensures participation under conditions of intermittent connectivity but also at the same time allowing to overjump evolutionary, intermediary steps made in the western world. These foundational enablers build the base upon which all other transformation efforts rely.

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2. Embedding digital systems within local economic logics

Digitalisation must resonate with existing economic structures and people's behaviour. Hybrid trade – where formal and informal systems coexist – is predominant across African agrifood markets. Digital tools must support payment with mobile phone (GSM), allow hybrid record-keeping, provide low-literacy interfaces and recognise informal governance structures such as market queens, elders, associations and cooperatives. These actors are central to dispute resolution, quality control and informal regulation. Rather than viewing informality as a barrier, digitalisation should treat informal institutions as critical partners that maintain order and continuity within markets – pathing to way to innovative business cases.

3. Strengthening human capacity and social diffusion

Digital literacy is best built through embedded and practice-oriented learning. Training should be local, multilingual and carried out in the spaces where agricultural work occurs, and workers meet. Demonstration-based learning, peer-to-peer exchange and women-led training groups enhance adoption. The STREAMING Survey reveals that users prefer relational learning models over classroom-style instruction. Drawing on Scott's concept of *metis* (local practical knowledge), digital uptake accelerates when new tools complement existing competencies and lived experiences [205].

4. Creating adaptive and culturally grounded standards

Standards enable data quality, traceability and interoperability, offering globally consistent practices and guidelines, but their implementation must be context-specific and flexible. A tiered approach allows actors to start with basic product identifiers (such as GTIN on product level with barcodes or at the most on batch-level with QR codes) and gradually transition to more advanced standards as capacity and market incentives grow. Co-creation is essential: farmers, aggregators, traders, processors and regulators must jointly define what constitutes legal compliance, quality, traceability and safety. This avoids mismatches between imported standards and local realities such as culturally rooted quality perceptions or context-specific post-harvest practices.

5. Strengthening governance and coordination mechanisms

Governance fragmentation remains a core challenge. A robust transformation pathway requires national digital agriculture coordination units, cross-ministerial platforms, interoperable data systems and transparent public repositories of digital initiatives. Integrating informal governance structures into formal coordination mechanisms increases legitimacy, promotes accountability and supports the social sustainability of digitalisation efforts. This aligns digital transformation with Agenda 2063's vision of inclusive, people-centred development.

6. Promoting inclusion: gender, informal actors and child labour

Digital transformation must purposefully address structural inequalities. Women face disproportionate barriers in literacy, mobility, device access and financial inclusion. Informal actors – including market carriers, itinerant labourers and small-scale traders – risk exclusion if digital systems require formal registration or constant connectivity. Ethnographic insights from Market Money and the chapter "Kinder des Marktes: Nachtrag" underscore that children

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also play active economic roles in informal markets. Research by Nieuwenhuys (1996), Montgomery (2009) and Alber (2001) demonstrates that children's labour must be understood within household strategies, socialisation processes and local moral economies. Digitalisation should avoid punitive or surveillance-oriented approaches that increase vulnerability. Instead,

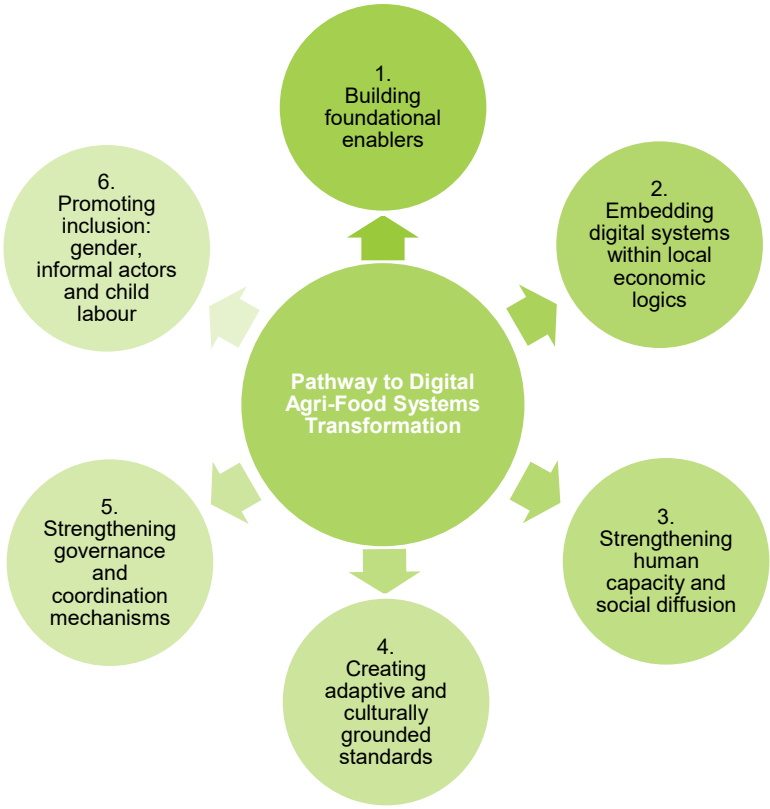


Figure 61: Visual representation of pathways toward digital agri-food systems transformation

systems should safeguard minors, integrate social protection actors and enhance youth-focused skills development while maintaining awareness of local socio-economic realities.

7.2. Conclusion: Towards a digitally enhanced agricultural future

Digital agricultural transformation represents a shift in the governance, social organisation and institutional structure of agrifood systems. A successful transformation pathway must therefore be inclusive, context-sensitive and aligned with African realities. It requires strong foundational infrastructure, adaptive standards implementation, embedded training ecosystems, coherent governance structures and a commitment to protecting the most vulnerable market actors, including women and children. When co-designed accordingly, digitalisation can advance the aspirations of Agenda 2063, strengthen regional integration and enhance the livelihoods and resilience of millions across the continent.

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Annex

Annex I – Overview Sections Sub-Questions and Evidence

- Desk research (**DR**)
- Systematic Literature Review (**SLR**)
- Trade and Digitalisation datasets (**TD**)
- Case studies (**CS**)
- Policy & Regulatory Framework analysis (**P&R**)
- Survey study (**S**)

Table 11: Sub-questions and location in report

Sub-questions	Sections	Evidence
1. *What is the current state of Africa's food systems, agricultural trade, and agreements?*	2.1 Background African's Food Systems 2.2 State of Africa's Agricultural Production and Trade Dynamics 2.3 Trade agreement & commitments 2.4 Current State of Inter-African and External Trade 2.5 Current State of Intra-African Agricultural Trade	DR, TD
2. *Which regulatory frameworks currently support digital agricultural trade, and how do they support cross-border paperless trade?*	2.3 Trade Agreements & Commitments 3.3 Institutional and Regulatory Frameworks Supporting Digitalisation in Agricultural Trade *Indirect insights through case studies: 4.3 Cassava, 4.4 Tea, 4.5 GS1 Rwanda*	DR, P&R, TD, CS
3. *How widely are relevant global standards adopted in African agricultural trade and how have these evolved over time?*	3.3 & 3.4 National Digital Trade Strategies & Performance (adoption of standards) 5.1 History of Digital Landscape Standards Supporting Agricultural Trade 5.2 Future Outlook of the AU Digital Landscape	P&R, TD, DR
4. *What types of digital agricultural solutions are currently being used across Africa and what do case studies reveal about success, challenges and opportunities of digital tools?*	4.1 Overview of Digital Solutions and Tools 4.2 Cassava Case Study 4.3 Tea Case Study 4.4 GS1 Rwanda Case Study	SLR, DR, CS
5. *What are the gaps between the current state of digital solutions and the ideal future state required under AfCFTA and Africa-EU trade aspirations?*	All sections under Questions 1–4 4.5 GS1 Rwanda (example of a more "ideal" future state) 5.2 Future Outlook of the AU Digital Landscape 6.1–6.3 Gap analysis / opportunities / alignment to Agenda 2063 7.1 Pathway to Digital Agricultural Transformation & Recommendations	DR, SLR, S, CS, P&R
6. *Which opportunities are arising from agricultural transformation to strengthen and accelerate agricultural production, quality assurances, transparency and market access?*	6.2 Opportunities Emerging from Digital Transformation 7.1 Moving Forward / Recommendations	DR, S, P&R
7. *What actions, policies and continental strategies are needed to accelerate trade digitalisation and digital innovation to enhance cross-border interoperability and support smallholder farmers and SMEs?*	3.3.3 National Digital Trade Strategies & Performance 4.2 SLR: Adoption Drivers & Performance (new section added) 5.2 Future Outlook of the AU Digital Landscape Chapters 6 & 7 – Policy implications and transformation pathways	TD, P&R, SLR, S, DR

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Annex II - Methodological approach

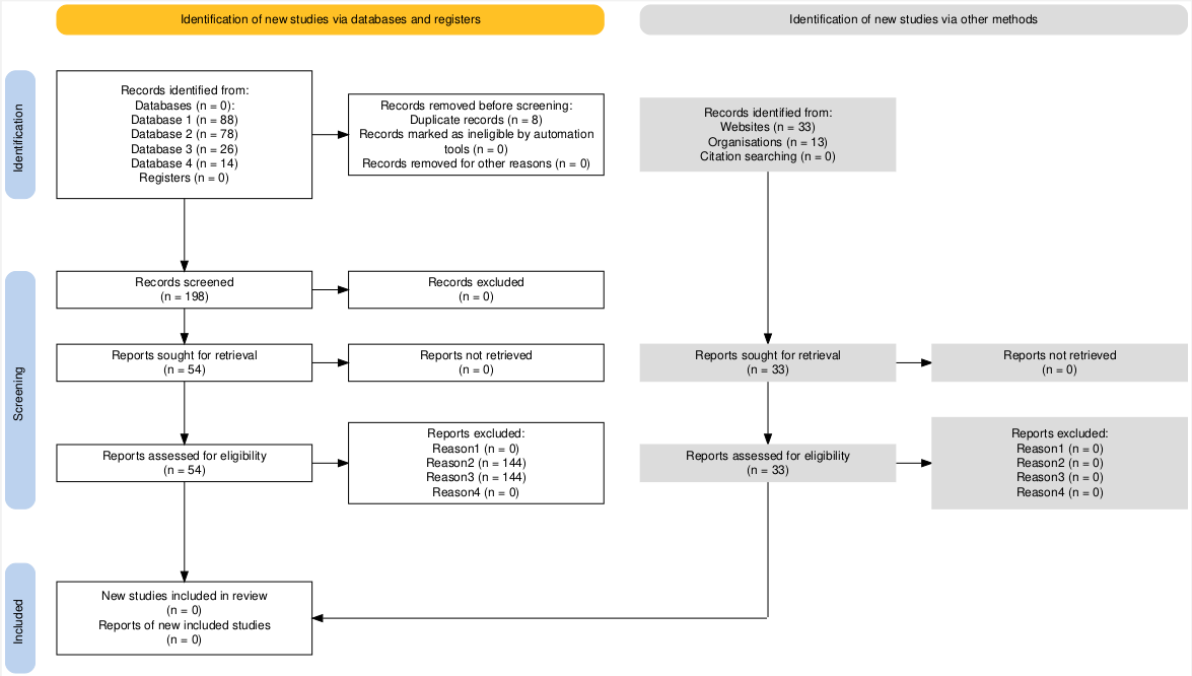


Figure 62: PRISMA flowchart SLR

Systemic Literature Search and Review

A systematic approach of conducting academic and grey sources has been conducted, consisting of combining Kitchenham et al. and the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) approach [9], [10], [11]. The review process involved 1) forming relevant research questions (as described before), 2) defining the search criteria which involves the selection of (academic) databases, search strings and inclusion & exclusion criteria, 3) developing a data extraction method and 4) reporting of the findings. Sources included 55 articles deemed eligible across four databases, with five additional reports from grey sources.

Research questions

Currently, the agricultural value chain in the AU consists of insights that are scarce, fragmented, and underreported, particularly on digitalisation of trade and food safety & quality standards [12]. To address this knowledge gap, three research questions were created, putting a focus on investigating and mapping the status of the digitalisation (trade) landscape of agricultural produce. This review aims to shed insight into the status of digital standards, tools and initiatives in the AU, identifying opportunities for targeted interventions, policymaking and improving support for small-scale farmers.

Search criteria

A search for literature across Scopus, Science Direct, Web of Science and Institute of Electric and Electronics Engineers Xplore (IEEE Xplore) was performed. Academic sources were collected in English and limited to publications between 2000 till 2025 to capture both foundational as recent sources. Several iterations of search strings were developed and

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adapted to align with the technical search requirements of the four databases. See Table 12 for the search strings.

Table 12: Keywords and search criteria

Keywords digital agriculture, agriculture 4.0, agricultural value chain, digitalization, digital standards, trade, import, export, track & tracing, food safety
Search Boolean ("Trade" **OR** "Import" **OR** "Export" **OR** "Market access" **OR** "Value chain" **OR** "Supply chain" **OR** "Supply Chain Management" **OR** "Agricultural trade" **OR** "Cross-border trade" **OR** "Traceability" **OR** "Certification" **OR** "Compliance" **OR** 'Food safety" **OR** "Regulatory framework" **OR** "Agri-food trade" **OR** "product standards" **OR** "Agrifood standards" **OR** "Non-tariff barriers" **OR** "Trade logistics") **AND** ("Digital Agriculture" **OR** "Agriculture 4.0" **OR** "Agricultural Value Chain") **AND** ("Digitalization" OR "Digitalisation" **OR** "Standards" **OR** "Digital Standards") **AND** (*55 AU countries[1]) **OR** ("Sub-Saharan Africa" **OR** "SSA" **OR** "Africa" **OR** "African Union" **OR** "MENA" **OR** "Middle East and North Africa region" **OR** "Middle-East and North Africa")
Inclusion criteria:
1. Articles published in English between 2000 and 2025.
2. Articles focusing on the agricultural domain within the AU.
3. Studies that explicitly mention digital tools, digitalisation of trade, certification and track & tracing standards or supply chain management.
4. Peer-reviewed articles in journals, conference papers and relevant grey literature sources.
Exclusion criteria:
1. Non-English publications.
2. Studies unrelated to the agricultural domain or digitalization standards & tools on trade.
3. Studies that are not focusing on member states in the AU.
4. Inaccessible articles.

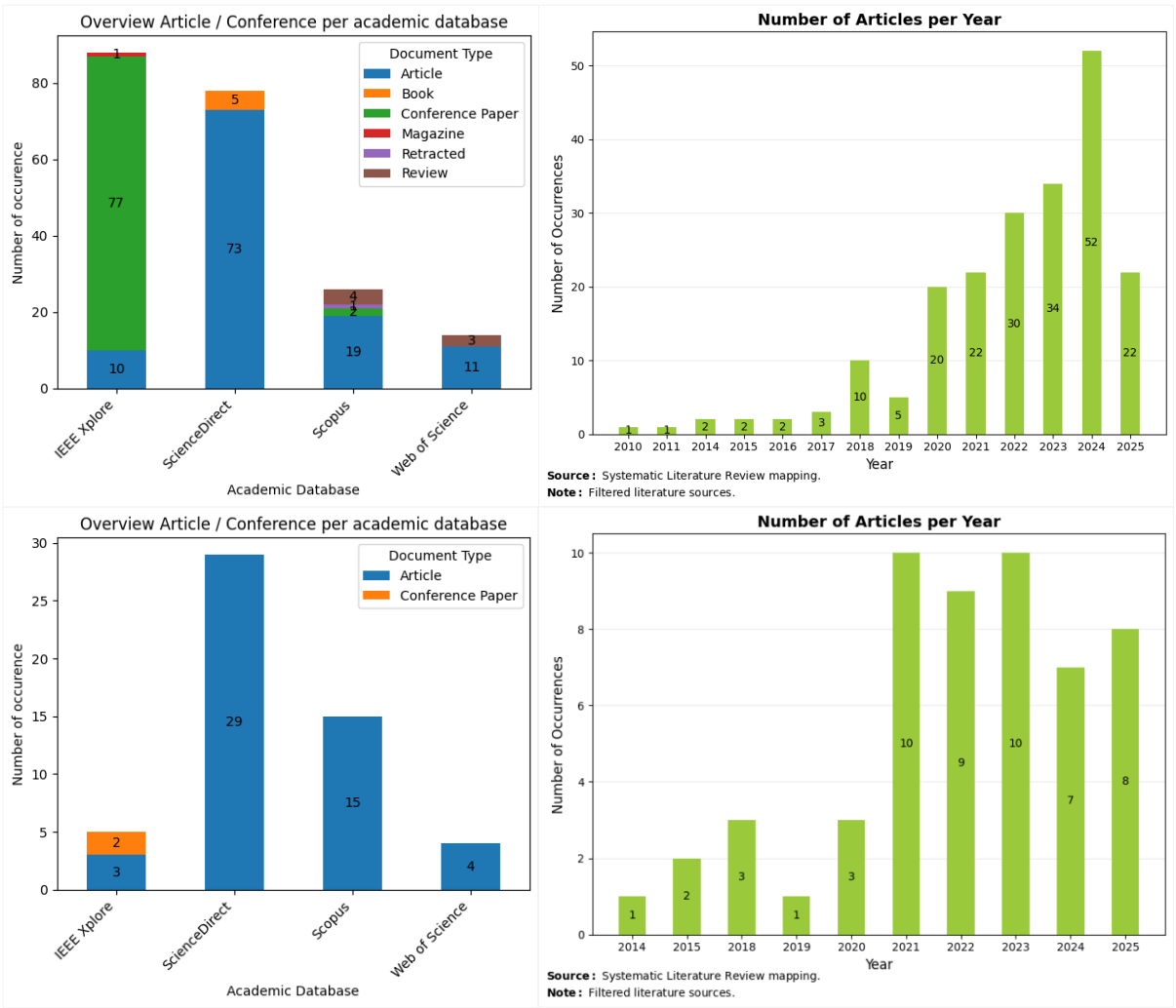


Figure 63: (L) Number of different types of documents per database unfiltered. The search was conducted using the keywords in table 1. (R) Overview of the publication dates of the articles

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The data extraction method follows guidelines from the PRISMA & Kitchenham protocol. Academic sources are exported with the database-specific export function, followed by importing the results in a standardized Excel file for systematic analysis. The following data from the academic papers will be extracted:

Table 13: Data extraction SLR

Topics	Contents
Source	Study ID (abvr. academic database, followed by number), General ID (ordered number regardless of database), authors, title & abstract, journal / publication type, full citation, contact details, URL/DOI
Eligibility Score	Content eligibility (method, geography, topic, trade relevance, year), inclusion/exclusion justification, final eligibility classification
Method	Study method / evidence type
Descriptive	Country / Region, Food system, Trade scop, actors
Digitalisation	Digital technologies, digital standards, digital extension service, digital financial service, digital marketing, digital farm management
Outcomes / Results	Adoption Drivers, Barriers & Challenges, Key Insights, Limitation & Research Gaps, Recommendations
Miscellaneous	Clarification Digitalisation and/or Outcomes/Results, miscellaneous reviewer comments or context-specific findings

For grey literature, a similar approach has been applied. The following metadata will be extracted: publication organization, document type, authors (if applicable), year or publication date, geographics and relevance to digitalisation of AU food systems (see Table 13). To ensure comparability and standardization with the academic sources; research questions, methods and hypothesis will also be extracted where possible.

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Annex III – Trade Integration Index 2.0

Figure 64 showcases the full measures of the 12 pillars from the Regional Digital Trade Integration Index 2.0

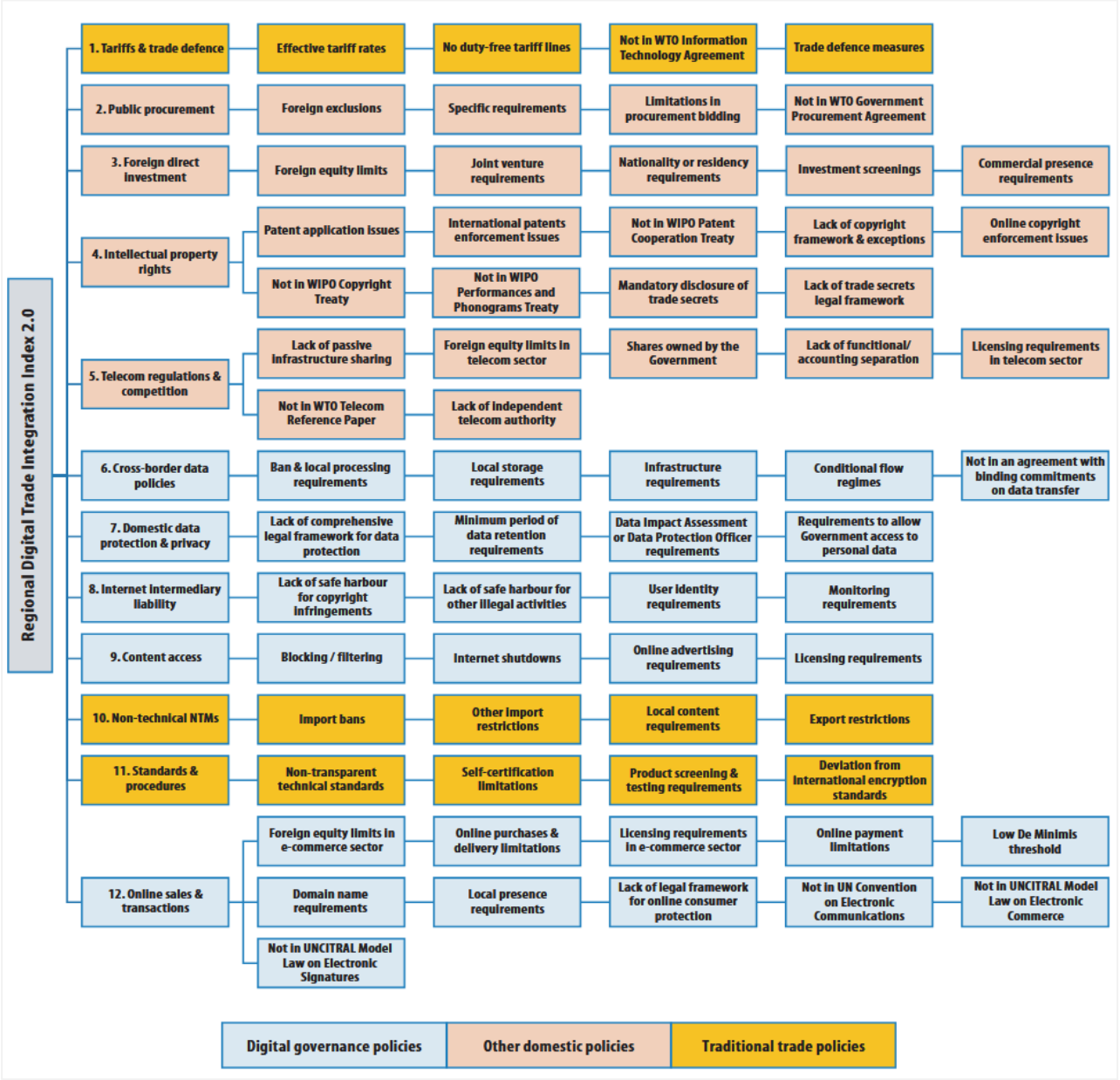


Figure 64: Framework and Components of the Regional Digital Trade Integration Index 2.0 (Source: RDTII 2.0: A guide UN-ESCAP, Figure 2)

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Annex IV – UN Global Survey on Digital and Sustainable Trade Facilitation

Figure 65 shows the full list of measurements assessed for the UN Digital and Sustainable Trade Facilitation Survey 2025.

Table 2

Grouping of trade facilitation measures and correspondence with trade facilitation agreement articles

Groups	Sub-groups	Measures	Relevant TFA Articles
General Trade Facilitation	Transparency	Online publication of import-export regulations	1.2
		Stakeholder consultation on draft regulations	2.2
		Advance publication/notification of trade regulations	2.1
		Advance rulings on import tariff classification and origin	3
		Independent appeal mechanism	4
	Formalities	Risk management	7.4
		Pre-arrival processing	7.1
		Post-clearance audits	7.5
		Separating release from final Customs duties determination	7.3
		Establishment and publication of average release times	7.6
		Trade facilitation measures for authorized operators	7.7
		Expedited shipments	7.8
		Acceptance of copies for trade formalities	10.2.1
	Institutional arrangement and cooperation	National committee on trade facilitation	23
		National legislative framework for border agency cooperation	8
		Agencies delegating border controls to Customs	
		Alignment of working days/hours with neighbouring economies at borders	8.2(a)
		Alignment of formalities/procedures with neighbouring economies at borders	8.2(b)
	Transit facilitation	Transit facilitation agreement(s)	
		Limit physical inspections/Use risk assessment for transit goods	10.5
		Pre-arrival processing for transit facilitation	11.9
		Cooperation between agencies of economies involved in transit	11.16
Digital Trade Facilitation	Paperless trade	Automated Customs System	
		Internet access for Customs and border agencies	
		E-Single Window System	10.4
		E-Submission of Customs declarations	
		E-Submission and issuance of import/export permits	
		E-Submission of Sea Cargo Manifests	
		E-Submission of Air Cargo Manifests	
		E-Application/issuance of Preferential Certificates of Origin	
		E-Payment of Customs duties	7.2
		E-Application for Customs refunds	

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Table 2. *(continued)*

Groups	Sub-groups	Measures	Relevant TFA Articles
Digital Trade Facilitation *(continued)*	Cross-border paperless trade	Laws and regulations for electronic transactions	
		Legal framework for digital authentication	
		Electronic exchange of Customs declaration	
		Electronic exchange of Certificate of Origin	
		Electronic exchange of Sanitary & Phyto-Sanitary Certificate	
		Paperless collection of payment from letters of credit	
Sustainable Trade Facilitation	Trade facilitation for SMEs	Trade-related information measures for SMEs	
		SMEs in AEO scheme	
		SMEs access Single Window	
		SMEs in national committee(s) on trade facilitation	
		Other special measures for SMEs	
	Agricultural trade facilitation	SPS testing and laboratory facilities	7.9
		SPS national standards and accreditation bodies	
		E-Application/issuance of SPS certificates	
		Special treatment for perishable goods	
	Trade facilitation and women	Trade facilitation policy/strategy for women's participation	
		Trade facilitation measures benefiting women	
		Women membership in national committee(s) on trade facilitation	
Other Trade Facilitation	Trade facilitation for e-commerce	Legal framework to facilitate cross-border e-commerce	
		Customs duties waived on small value shipments	
		Immediate release procedures for e-commerce goods	
		AEO program for cross-border e-commerce	
		E-Submission of Customs declarations by postal operators/express carriers	
	Green trade facilitation	Facilitation of sustainability reporting for traded goods	
		Trade facilitation of green and climate-smart goods	
		eCITES application/issuance/exchange	
		Facilitation of legitimate trade in waste	
	Trade finance for trade facilitation	Single Window facilitates traders access to finance	
		Authorities engaged in emerging tech project(s) covering trade finance	
		Variety of trade finance services available	

Figure 65: Grouping of Trade Facilitation Measures for the UN Survey on Digital and Sustainable Trade Facilitation in 2025 (Source: Global Report 2025 UN-ESCAP, Table 2) [69]

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Annex V – Tea Producer Rwanda

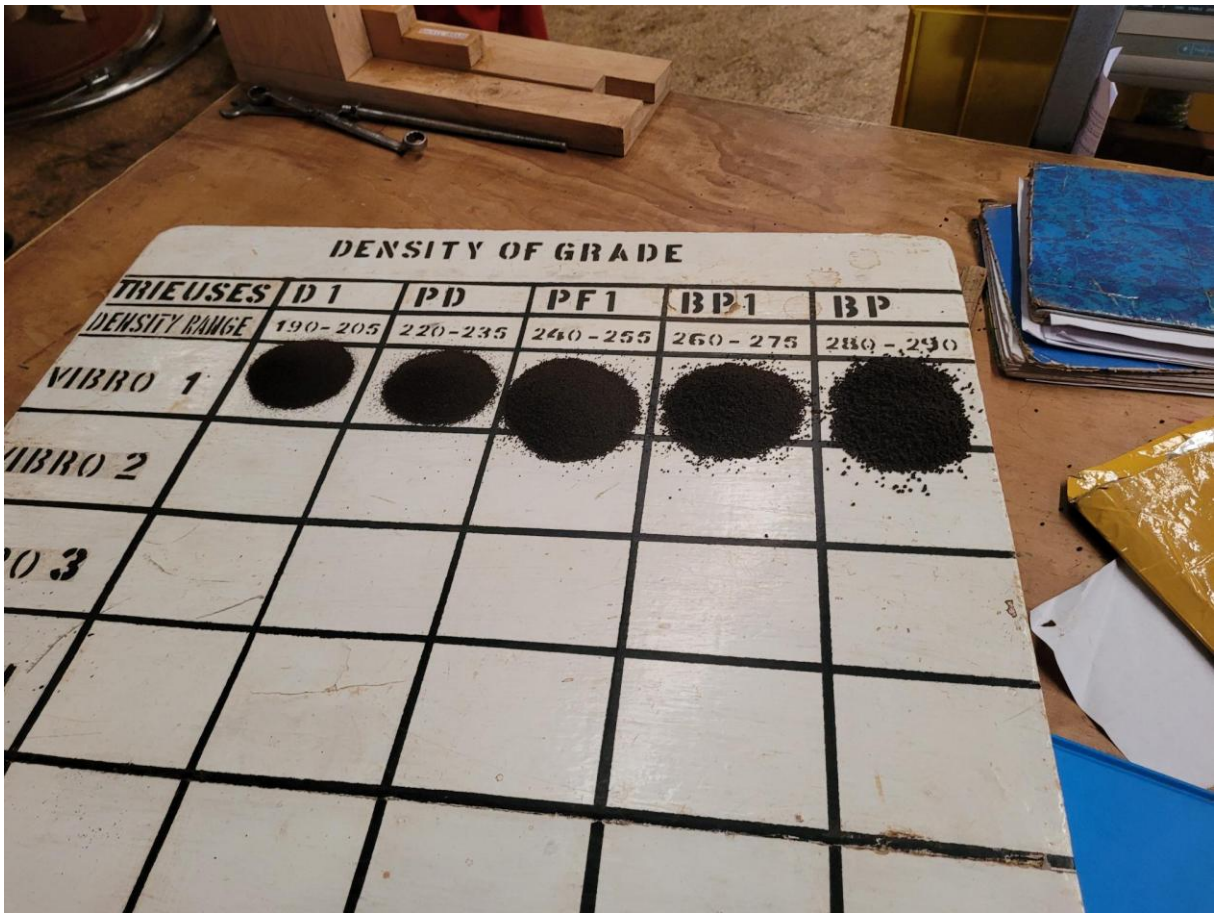
The following pictures were taken during a field visit to a Rwandan tea cooperative in 2022 and 2025.





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Annex VI – Hofstede's Cultural Dimensions

Power distance index (PDI): *"Power Distance is the extent to which the less powerful members of organizations and institutions (like the family) accept and expect that power is distributed unequally. This dimension is thought to date from the advent of agriculture, and with it, of large-scale societies. Until that time, a person would know their group members and leaders personally. This is not possible where tens of thousands and more have to coordinate their lives. Without acceptance of leadership by powerful entities, none of today's societies could run."*

Individualism vs. collectivism (IDV): *"Individualism is the extent to which people feel independent, as opposed to being interdependent as members of larger wholes. individualism does not mean egoism. It means that individual choices and decisions are expected. Collectivism does not mean closeness. It means that one "knows one's place" in life, which is determined socially."*

Uncertainty avoidance index (UAI): *"Uncertainty avoidance deals with a society's tolerance for uncertainty and ambiguity. Uncertainty avoidance has nothing to do with risk avoidance, nor with following rules. It has to do with anxiety and distrust in the face of the unknown, and conversely, with a wish to have fixed habits and rituals, and to know the truth."*

Masculinity vs. femininity (MAS): *"Masculinity is the extent to which the use of force in endorsed socially. This is NOT about individuals but about expected emotional gender roles. Masculine societies are much more openly gendered than feminine societies."*

Long-term orientation vs. short-term orientation (LTO): *"Long-term orientation deals with change. In a long-time-oriented culture, the basic notion about the world is that it is in flux, and preparing for the future is always needed. In a short-time-oriented culture, the world is essentially as it was created, so that the past provides a moral compass, and adhering to it is morally good. As you can imagine, this dimension predicts life philosophies, religiosity, and educational achievement."*

Indulgence vs. restraint (IND): *"Indulgence is about the good things in life. In an indulgent culture it is good to be free. Doing what your impulses want you to do, is good. Friends are important and life makes sense. In a restrained culture, the feeling is that life is hard, and duty, not freedom, is the normal state of being."*

Source: The 6-D model of national culture. [206]

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Annex VII – Initial STREAMING Survey (2025)

Table 14 showcases the structure of the initial survey sent to partner institutes in Africa with its primary purpose to obtain basic information among 12 sections from the STREAMING project partners. In addition, the results will be used to create further questionnaires for specific target groups. For a further explanation of the survey results, please consult D3.2: Policy Recommendations for digital adoption and scaling-up.

Figure 66 illustrates the included African partner countries who participated in the survey.

Table 15 provides a synopsis of the collected answers.

Table 14: Questionnaire on Agriculture, Trade and Digitalisation in African Partner Countries

Question No.	Section	Question
1	**Respondent & Background**	Date of response
2	**Respondent & Background**	Name
3	**Respondent & Background**	E-mail contact
4	**Respondent & Background**	Country
5	**Respondent & Background**	Institution
6	**General Agricultural Context**	How many farmers are living in your country? (approx.)
7	**Agricultural Production**	Which agricultural products are mainly produced in your country? (Multiple answers possible)
8	**Agricultural Production**	Are any products missing from this list? If yes, please list them.
9	**Trade & Distribution**	With which agricultural products does your country trade within the African Union? (Multiple answers possible)
10	**Trade & Distribution**	With which agricultural products does your country trade outside the African Union? (Multiple answers possible)
11	**Trade & Distribution**	Which languages are mainly used for trade?
12	**General Agricultural Context**	What is the main source of food in your country?
13	**General Agricultural Context**	Is there malnutrition in your country and if so, what reasons can you give?
14	**Finance & Payments**	Which payment methods are used in your country?
15	**Finance & Payments**	What percentage of the population has a bank account?
16	**Finance & Payments**	What percentage of the population has a smart phone?
17	**Trade & Distribution**	To which countries / regions are products distributed?
18	**Digitalisation & Technology**	In which areas are digital solutions used in agriculture? (Multiple answers possible)
19	**Digitalisation & Technology**	Which technologies are used? (Multiple answers possible)
20	**Digitalisation & Technology**	If there are online platforms used in the agricultural sector or in trade, please list them (with links):
21	**Digitalisation & Technology**	Is the content in those platforms locally developed or are they developed for international use?
22	**Digitalisation & Technology**	Are there online platforms for standardization, traceability, product information and trade? If yes, please list them.
23	**Digitalisation & Technology**	What percentage of farmers are using those platforms?

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24	**Energy, Inputs & Resources**	Which energy sources are used? (Multiple answers possible)
25	**Energy, Inputs & Resources**	What kind of fertilizers are mostly used in your country?
26	**Energy, Inputs & Resources**	What kind of pesticide do you use?
27	**Sustainability & Ethics**	How important is organic farming in your country? Please describe briefly:
28	**Sustainability & Ethics**	How important is climate-neutral and sustainable agriculture in your country? Please describe briefly:
29	**Sustainability & Ethics**	How important is animal welfare in your country? Please describe briefly:
30	**Policies & Laws**	Are there initiatives and laws in your country that effectively support farmers? Please list them.
31	**Policies & Laws**	Are there laws and structural conditions that make agricultural production more difficult? Please list them.
32	**Agricultural Structure**	How many farms of what size are there in your country? (e.g. X Large farms with industrial production, X small farms for local trade etc.)
33	**Agricultural Structure**	Is the agricultural sector in your country rather formal or informal? Please elaborate briefly.
34	**Challenges**	In your opinion, what are the biggest challenges for sustainable, resource-conserving and climate-friendly production?
35	**Challenges**	In your opinion, what are the biggest challenges for high-yield, efficient production?
36	**Challenges**	In your opinion, what are the biggest challenges for profitable trade within the AU?
37	**Challenges**	In your opinion, what are the biggest challenges for profitable trade outside the AU?
38	**Social Issues & Inclusion**	In your opinion, what are the biggest challenges for fair working conditions and good wages?
39	**Social Issues & Inclusion**	In your opinion, what are the biggest challenges for animal welfare?
40	**Social Issues & Inclusion**	Is there child labor in agriculture? If yes, what kind? (Multiple answers possible)
41	**Social Issues & Inclusion**	Are there initiatives to involve vulnerable groups in agriculture? If yes, please specify:
42	**Solutions & Outlook**	Are there obvious solutions to agricultural challenges in your country?
43	**Solutions & Outlook**	Are there obvious solutions for more profitable trade in agricultural products?
44	**Solutions & Outlook**	What digital solutions do you think would improve yield, sustainability and profit in agriculture?
45	**Policies & Laws**	Would you say that existing EU laws are more helpful or more of a hindrance to your agriculture?
46	**Vision & Hypotheticals**	Let's say your country wins billions in the lottery and is only allowed to spend the money on agriculture. What would you buy? What would you change?
47	**Vision & Hypotheticals**	And now let's say it's not an institution, you or your country that would win the lottery, but the farmers and they would be allowed to spend their winnings on anything they want. What percentage would remain farmers?
48	**Final Feedback**	Do you think I have forgotten any important questions? Please add them here:

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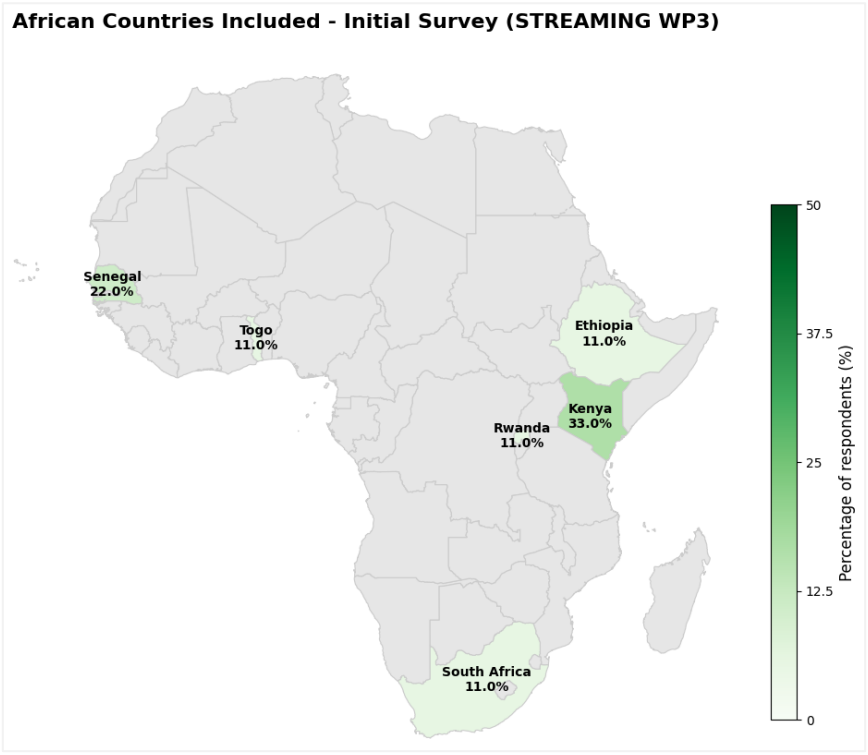


Figure 66: Included African Countries Initial Survey

Table 15: Most Frequent Responses to Questions 6-48

Question No.	Section	Question
1	**Respondent & Background**	-
2	**Respondent & Background**	-
3	**Respondent & Background**	-
4	**Respondent & Background**	-
5	**Respondent & Background**	-
6	**General Agricultural Context**	The estimated number of farmers per country most commonly ranged between 1 and 5 million.
7	**Agricultural Production**	The main agricultural products reported were maize, rice, grains, potatoes, beans, vegetables, wheat, coffee and cotton.
8	**Agricultural Production**	Frequently mentioned missing products included cashew nuts, tea and cocoa.
9	**Trade & Distribution**	Intra-African Union trade mainly involved coffee, tea, sugar, cotton, fruit.
10	**Trade & Distribution**	Trade outside the African Union focused primarily on coffee, tea, cocoa and sugar.
11	**Trade & Distribution**	English, French and Arabic were the most commonly used trade languages.
12	**General Agricultural Context**	The main food sources reported were maize, rice and wheat.
13	**General Agricultural Context**	Undernutrition was reported in many countries, mainly attributed to poverty, low agricultural productivity and climate change.
14	**Finance & Payments**	The most commonly used payment methods were cash, mobile money and bank transfers.
15	**Finance & Payments**	Bank account ownership was most often estimated at between 20% and 50% of the population, with an outlier of 85%.

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16	**Finance & Payments**	Smartphone penetration was generally estimated between 30% and 60% of the population, with an outlier of 91%.
17	**Trade & Distribution**	Agricultural products were mainly distributed to neighbouring countries and the European Union.
18	**Digitalisation & Technology**	Digital solutions were most frequently used for irrigation, crop monitoring and market information.
19	**Digitalisation & Technology**	Commonly used technologies included drones, sensors and mobile applications.
20	**Digitalisation & Technology**	Reported online platforms mainly consisted of local marketplaces and international trading platforms (e.g., HaloChoice, AgriKool, TonnUp, PrysWys, Trigga).
21	**Digitalisation & Technology**	Platform content was most often described as a combination of locally developed and internationally oriented material.
22	**Digitalisation & Technology**	Platforms for standardisation and traceability were reported, mainly at national level or through international systems.
23	**Digitalisation & Technology**	Platform usage among farmers was generally estimated between 10% and 30%.
24	**Energy, Inputs & Resources**	Energy use in agriculture relied primarily on solar energy, diesel and biomass.
25	**Energy, Inputs & Resources**	Both chemical and organic fertilisers were widely reported as being used.
26	**Energy, Inputs & Resources**	The use of both chemical and biological pesticides was commonly reported.
27	**Sustainability & Ethics**	Organic farming was generally described as growing in importance.
28	**Sustainability & Ethics**	Climate-neutral and sustainable agriculture was widely perceived as highly important.
29	**Sustainability & Ethics**	Animal welfare was reported as an increasingly relevant issue.
30	**Policies & Laws**	Farmer support measures mainly included subsidies, training programmes and technical assistance.
31	**Policies & Laws**	Bureaucratic barriers and insufficient infrastructure were the most frequently cited constraints.
32	**Agricultural Structure**	Most countries reported a mixed structure of large-scale and smallholder farms, with SA reporting 86 mln ha large farms / 14.5 mln ha smallholder farmers.
33	**Agricultural Structure**	The agricultural sector was commonly described as containing both formal and informal elements.
34	**Challenges**	Key challenges for sustainable production included climate change, water scarcity and limited financing.
35	**Challenges**	Efficient and high-yield production was constrained by limited technology, skills gaps and financing challenges.
36	**Challenges**	Intra-African Union trade was hindered mainly by trade barriers, infrastructure gaps and bureaucracy.
37	**Challenges**	Similar barriers were reported for trade outside the African Union.
38	**Social Issues & Inclusion**	Fair wages and working conditions were constrained by weak legal frameworks, limited enforcement and economic instability.
39	**Social Issues & Inclusion**	Animal welfare challenges were linked to regulatory gaps, enforcement issues and economic pressures.
40	**Social Issues & Inclusion**	Child labour was reported, mainly in the form of family-based agricultural work.
41	**Social Issues & Inclusion**	Inclusion initiatives for vulnerable groups mainly focused on training and financial support.
42	**Solutions & Outlook**	Proposed solutions to agricultural challenges centred on technological innovation and improved access to finance.
43	**Solutions & Outlook**	Solutions for more profitable trade focused on improved trade agreements and better infrastructure.

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44	**Solutions & Outlook**	Mobile applications, sensors and drones were most frequently identified as promising digital solutions.
45	**Policies & Laws**	EU legislation was generally perceived as having both supportive and constraining effects.
46	**Vision & Hypotheticals**	Hypothetical investment priorities focused on infrastructure, technology and training.
47	**Vision & Hypotheticals**	Most respondents believed that a majority of farmers would remain in agriculture if financially empowered.
48	**Final Feedback**	Respondents generally considered the questionnaire to be comprehensive, with no major gaps identified.

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Annex VIII – Sources of Images

Figure 40: Exemplary cassava supply chain for the production of cassava flower based on Pingmuanglek et al. (2017) and Tambun & Manik (2021) – own illustration (see Annex VIII – Sources of Images) [155], [156]. Images sourced from (start to finish):

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- Flickr.com[38]
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- Wikimedia Commons [40]

Figure 44: Exemplary Tea Value Chain, adapted from Foster & Graham (2024) – own illustration (see Annex VIII – Sources of Images) [179]**.** Images sourced from (start to finish):

- Pixabay.com[41]
- Pixabay.com [42]
- Field trip
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- Field trip
- Field trip
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- Field trip
- sorwatheltd.rw[46]

[26] "Cassava seed (14913272466).jpg" by Ton Rulkens, CC BY-SA 2.0
[27] "Cassava Plus" by IFDC Photography, CC BY-NC-SA 2.0
[28] "Farmers harvesting cassava roots" by International Institute of Tropical Agriculture, CC BY-NC 2.0
[29] https://www.freepik.com/free-photo/arrangement-nutritious-cassava-roots_18037115.htm
[30] https://www.synergos.org/sites/default/files/inline-images/inline-2016-kogi-and-benue-adolphus-opara-45.JPG
[31] "Thailand 30" by Alliance of Bioversity International and CIAT, CC BY-SA 2.0
[32] "Cassava Delivery Truck" by IFPRI, CC BY-NC-ND 2.0
[33] "Fabricated cassava processing machines" by International Institute of Tropical Agriculture, CC BY-NC 2.0
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[35] "Fufu Machine" by Flixtey, CC BY-SA 3.0
[36] "Sun drying fermented cassava chips" by International Institute of Tropical Agriculture, CC BY-NC 2.0
[37] "Rwanda Cultural Day | San Francisco, 24 September 2016" by Paul Kagame, CC BY-NC-ND 2.0
[38] "Gari, also known as cassava flour" by World Bank Photo Collection, CC BY-NC-ND 2.0
[39] "Deep Fried Cassava Chips" by Cmumbe, CC BY-SA 4.0
[40] "Cassava (2).jpg" by Renatosjoao, CC BY-SA 4.0
[41] https://pixabay.com/nl/photos/thee-blad-plant-natuur-takje-3292827/
[42] https://pixabay.com/photos/tea-leaves-mountain-leaf-tea-leaf-4547923/
[43] https://pixabay.com/photos/tea-market-organic-ingredient-6786614/
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[45] https://pixabay.com/photos/tea-leaves-hands-fresh-drying-623796/
[46] https://sorwatheltd.rw/wp-content/uploads/2025/01/8L7A3570-1200x596.jpg

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- Pixabay[47]

[47] https://pixabay.com/photos/justice-dish-hammer-auction-law-510742/

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