

## Data management system for sustainable agriculture among smallholder farmers in Tanzania: research-in-progress

Gilbert Exaud Mushi, Giovanna Di Marzo Serugendo & Pierre-Yves Burgi

**To cite this article:** Gilbert Exaud Mushi, Giovanna Di Marzo Serugendo & Pierre-Yves Burgi (2023) Data management system for sustainable agriculture among smallholder farmers in Tanzania: research-in-progress, *Information Technology for Development*, 29:4, 558-581, DOI: [10.1080/02681102.2023.2215528](https://doi.org/10.1080/02681102.2023.2215528)

**To link to this article:** <https://doi.org/10.1080/02681102.2023.2215528>



© 2023 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 31 May 2023.



[Submit your article to this journal](#)



Article views: 1446



[View related articles](#)






[View Crossmark data](#)



Citing articles: 2 [View citing articles](#)

# Data management system for sustainable agriculture among smallholder farmers in Tanzania: research-in-progress

Gilbert Exaud Mushi <sup>a,b</sup>, Giovanna Di Marzo Serugendo <sup>a</sup> and Pierre-Yves Burgi <sup>c</sup>

<sup>a</sup>Computer Science Centre, University of Geneva, Geneva, Switzerland; <sup>b</sup>Informatics and Information Technology, Sokoine University of Agriculture, Morogoro, Tanzania; <sup>c</sup>Division Système et Technologies de l'Information et de la Communication, University of Geneva, Geneva, Switzerland

## ABSTRACT



Smallholder farmers produce about 70% of the world's food and employ more than one billion people. They therefore have an important role to play in eradicating food insecurity and poverty among the world's growing population. Although there are different digital services for smallholder farmers, the existing services lack sustainability in the agriculture context and hardly meet their needs. Data management and sharing among different agriculture stakeholders has the potential to make agriculture sustainable, but there is a need to enable access to digital services in an entire farming cycle under one roof. This paper aims to propose the design of a comprehensive data management digital framework to solve common challenges of smallholder farmers in Tanzania and other countries' agricultural systems. We follow the design science research (DSR) method to develop an artifact that interacts with the problem context. To illustrate the framework's applicability, we use different case studies in Tanzania.

## KEYWORDS

Smallholder farmers; information system design; sustainable agriculture; farm data management; Tanzania

## 1. Introduction

The world's food demand is expected to increase by 35%–56% between 2010 and 2050 (van Dijk et al., 2021). The Food and Agriculture Organization of the United Nations (FAO) predicts a much larger increase in demand of 70% over the same period (FAO, 2009). This demand, linked to the estimated world population increase between 9.4 and 10.2 billion people by 2050, with Sub-Saharan Africa leading the growth rate by 114% (FAO, 2009), calls for action to increase the production and well-being of the society despite many challenges such as decreasing arable land, climate change, increased water demand, and environmental pollution. The question of eradicating global hunger and extreme poverty – Sustainable Development Goals (United Nations, 2015) – remains a major global societal challenge. Investing in smallholder farmers has the potential to eradicate food insecurity and extreme poverty globally. According to FAO (2021), smallholder farmers produce 70% of the world's food and employ more than one billion people, the majority living in rural and semi-urban areas. Agriculture is the backbone of the national economy in Tanzania (as in many other developing countries), and more than 70% are smallholder farmers (Chandra & Collis, 2021). Thus, agriculture is essential to increase income and food security, hence the need

**CONTACT** Gilbert Exaud Mushi  gilbert.mushi@etu.unige.ch, gilbert.mushi@sua.ac.tz  Computer Science Centre, University of Geneva, Centre Universitaire d'Informatique (CUI), Battelle, Bât. A, 7, rte de Drize, 1227 Carouge (GE), Switzerland, Geneva, Switzerland; Informatics and Information Technology, Sokoine University of Agriculture, Morogoro, 3038, Tanzania

© 2023 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group  
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

for a common approach to agricultural development that would allow smallholder farmers to participate in agri-business (ITU, 2016).

In this digital age, Information Technology (IT) is central to the development of political, economic and social aspects of human life. Smallholder farmers can potentially achieve sustainable agriculture through Information and Communication Technologies (ICTs). Furthermore, ICTs can significantly reduce poverty vulnerability of smallholder farmers by increasing their income and ability to make more informed decisions on various nonagricultural and matters related to agribusiness (Zhang et al., 2022). According to Smidt and Jokonya (2021), the adoption to ICTs solutions to support smallholder farmers requires the collaboration of different actors, including the government to create a comprehensive localized framework. Enabling smallholder farmers' participation in agribusiness through digital technologies is critical to the socio-economic development of agriculture value chains (AVCs) within and outside the country. The development of digital solutions for smallholder farmers and a strong political will to include vulnerable and marginalized people (such as rural women, youth and indigenous communities) in this process is important for sustainable development in small and medium income countries (FAO, 2021; Smidt & Jokonya, 2021).

Despite available advanced digital technology and other ICTs-related efforts to help smallholder farmers access essential services for sustainable farming, such farmers still face many challenges. Large-scale and commercial farmers have long used digital technology in agriculture (e.g. precision and smart farming) to manage farm activities and access services in a complete farming cycle (USAID, 2013). Agriculture industries develop comprehensive digital agricultural solutions such as sensing technology for field data collection, farm management information systems (FMISs) for acquiring and analyzing data, decision support systems, and variable rate technology to actuate real-time decisions (Saiz-Rubio & Rovira-Más, 2020). These cyber-physical technologies are mainly designed for high-income countries and require a substantial financial investment. Furthermore, precision agriculture and smart farming have shown great potential for sustainable agriculture – increased production and income and environmental conservation (Bhakta et al., 2019; Giray & Catal, 2021). Few recent studies in developing countries report the possibilities for adopting precision farming technologies, but many are still experimental (Onyango et al., 2021). Most smallholder farmers can hardly afford this kind of ICTs solution for sustainable agriculture.

There are many ICTs solutions developed to address challenges in agriculture and smallholder farmers ranging from simple mobile applications to web-based digital platforms. To mention a few, the ICTs solutions on dissemination of agricultural information and advisory services to farmers through different channels such as telecentres and agricultural knowledge centers (Birke & Knierim, 2020; Mtega, 2021; Sanga et al., 2014); farmers adoption of e-market (Cloete & Doens, 2008); and mobile applications for different crop and livestock value chains (FAO, 2018; Shapa et al., 2021). Moreover, some government are developing and implementing ICTs project to solve smallholder farmers challenges such as e-governance mediated agriculture in India (Behera et al., 2015) and a fertilizer recommendation system in Bangladesh (Hossain & Siddique, 2020). However, the existing ICTs solutions for smallholder farmers particularly in developing countries address a specific challenge, which requires a farmer to coordinate various solutions to obtain services in a complete farming cycle.

Considering the above, this article aims to answer the following questions: (1) 'What comprehensive digital framework could be designed so that smallholder farmers can access all the essential services of a complete farming cycle via a single access point?' – to answer this question, it is necessary to identify the common challenges faced by smallholder farmers and the services needed for a complete farming cycle; (2) 'How does the designed digital framework contribute to sustainable agriculture and development?' (3) 'What is the applicability of the designed digital framework in solving the existing smallholder farmers' challenges in Tanzania?' (4) 'What are the prerequisite infrastructures and other capabilities and resources for such a framework to be successfully implemented and sustainably operated?'

This paper is part of a larger study that aims to design and implement a digital framework for smallholder farmers to access all essential services (subsidies, credit, insurance, government services,

market, and farming information) under one roof. In a previous study (Mushi et al., 2022), we conducted a systematic literature review to identify common challenges of smallholder farmers with special attention in the Tanzanian case. According to Chandra and Collis (2021), the challenges identified in the Tanzanian case are more similar across developing countries. Therefore, the designed platform will potentially be helpful in many other developing countries. Such a platform could increase farm production and profitability while preserving the environment.

In this paper, we contribute to the field for IT for development by proposing a state-owned (or public-private) Farmers' Digital Information System (FDIS) framework. FDIS is a data management framework for development bringing together key stakeholders in agriculture to improve services' sustainability, monitoring various practices, and offering single access to essential services such as credit and insurance, subsidies, quality farm inputs, market, and advisory services. The framework provides such a single access to several essential actors: farmers, financial institutions, farm products consumers, agro-dealers, government agencies, and processing industries. We designed the FDIS framework for sustainable agriculture and illustrated its applicability through four case studies from Tanzania. We used the design science research method to develop the artifact solution for the common challenges of smallholder farmers in Tanzania. As part of the evaluation stage, we have shown the applicability of FDIS in solving smallholder farmers' problems such as access to subsidies, credit and insurance, quality farm inputs, and market services. In addition, we have illustrated the framework's viability in sustainable agriculture and development among smallholder farmers.

The main contribution of this paper is a proposed abstract design of the FDIS framework that integrates different modules (farmers' data, agro-dealers, farm inputs, advisory and market data module). We structured this paper into seven sections. Section 2 provides the theoretical framework of key IT for agriculture sector development; Section 3 describes the research methodology we applied to design the artifact solution; Section 4 presents the results of the study that covers different modules of the FDIS framework; Section 5 illustrates the FDIS framework applicability in four different Tanzanian cases; Section 6 discusses various issues related to the FDIS framework implementation, contribution to sustainable agriculture and development; finally, Section 7 concludes this paper with a summary of the artifact and future work.

## 2. Theoretical background

This section provides the theoretical background of our study, focusing on the key IT for agriculture sector development. It follows the theories of Information and Communication Technology for Development (ICT4D) by Qureshi (2015) and Zheng et al. (2018), in the sense that technological advancement should have an impact on people's lives, without copying and pasting theories and technologies created in the so-called 'developed countries' to 'developing countries.' By reviewing the literature, we identify cutting-edge ICTs in agriculture, ICTs used in small and medium income countries and specifically in the agriculture sector in Tanzania.

### 2.1 Modern ICTs in agriculture

Globally, precision agriculture (evolving to smart farming) is the leading cutting-edge digital solution that meets the needs of farmers in a complete farming cycle. It involves the use of sophisticated technologies such as the internet of things (IoT), farm information management systems (FIMs), artificial intelligence (AI), decision support systems (DSS), and variable rate applications or actuators (Saiz-Rubio & Rovira-Más, 2020). These components work autonomously to optimize farm input and yield forecasts and collaborate with other stakeholders such as services providers and the market, thereby improving sustainability in agriculture. In the Global North, digital farming platforms are usually owned by private companies that farmers and other stakeholders can subscribe to, normally for a fee. While these advanced digital platforms may not be applicable to developing countries (for example 365FarmNet, 2022), aspects such as the ability to record data even without Internet access

and data protection strategies could be useful for platforms being considered in the developing world.

Indeed, precision agriculture requires a substantial capital investment that smallholders can hardly afford. Therefore, in recent years, scientists and organizations developed a digital farmer profiling platform to enable smallholder farmers to access essential services in a complete farming cycle (Boyera et al., 2017; Gray et al., 2018). Service providers manage farmers' profiles for a fee paid by stakeholders, including farmers, to maintain the farmer profiling infrastructure. Stakeholders, such as financial institutions, automatically add fees to loans, which eventually affects the economy of smallholders. Such a digital profiling solution is still in the experimental stage and faces sustainability issues (Gray et al., 2018).

## **2.2 ICTs in lower and middle-income countries agriculture sector**

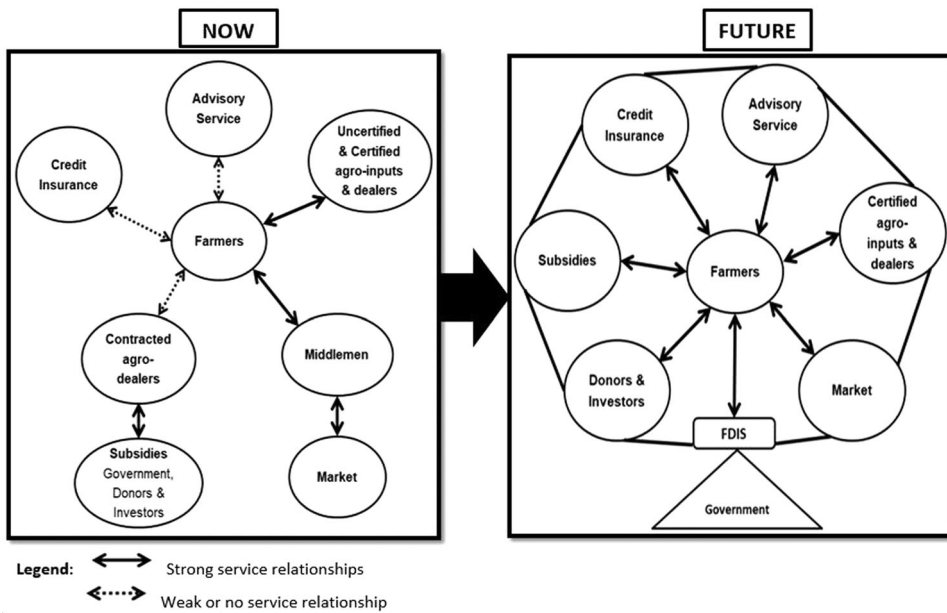
Many digital agricultural solutions have been developed in low- and middle-income countries, which cover many aspects of socio-economic development of farmers. They include strengthening market of agricultural products through e-market (Cloete & Doens, 2008), improving agricultural extension services (Namyenya et al., 2021; Sanga et al., 2014), and disseminating agricultural information for improved farming and decision making (Bello-Bravo et al., 2020; Krell et al., 2021; Maredia et al., 2018; Mtega, 2021). These solutions alleviate several challenges faced by farmers such as fighting counterfeit farm inputs (Shao & Edward, 2014), access to financial services and mobile payment (Kinuthia & Mabaya, 2017; Kirui et al., 2010; Wenner et al., 2018) and access to farm insurance (Osumba et al., 2020).

The adoption of precision agriculture by smallholder farmers in developing countries offers a promising future, but as already pointed out, these advanced IT projects are still in their infancy (Onyango et al., 2021). Also, each country has various digital services for smallholder farmers ranging from simple mobile applications to Web-based digital solutions, for instance: the Association for People of Haryana's (AFPOH) e-governance mediated agriculture project in India (Behera et al., 2015), the Kenyan Agriculture and Livestock Research Organization's (KALRO) mobile applications project for different value chains (FAO, 2018), and the online fertilizer recommendation to farmers in Bangladesh (Hossain & Siddique, 2020). The digital solutions in developing countries have sustainability issues and generally solve a specific farming problem or value chain. Thus, a digital framework solution for smallholder farmers that resolve common challenges in a complete farming cycle through single access point is lacking. Such a digital framework will contribute to the development of farmers economically through increased production and income and strengthen agricultural value chains in developing countries.

## **2.3 ICTs and Tanzania agriculture sector**

Since the adoption of ICTs in national development plans in 2003 (United Republic of Tanzania, 2003), Tanzania, like many other developing countries, has had various digital solutions addressing different farmers' challenges in different value chains, such as advisory services to farmers on various farming activities (Ortiz-Crespo et al., 2021; Sanga et al., 2013), access to market and market information (Hamill, 2017; Magesa et al., 2014) and combating substandard farm inputs (Shao & Edward, 2014) to ensure quality input for increased production and income. Many of these and other emerging digital solutions in agriculture operates in mobile application, influenced by high penetration of mobile devices (i.e smartphones) and Internet access.

Despite the existing digital solutions, smallholder farmers in Tanzania still face numerous challenges. These include poor access to subsidies (Masinjila & Lewis, 2018) and financial services (credit and insurance) (Kimaro, 2020), middlemen market disruption (Misaki et al., 2016; Navuri, 2018), substandard farm inputs (Shao & Edward, 2014), poor government control, and lack of personalized farming advisory and information services (Chandra & Collis, 2021). [Figure 1](#) shows the existing

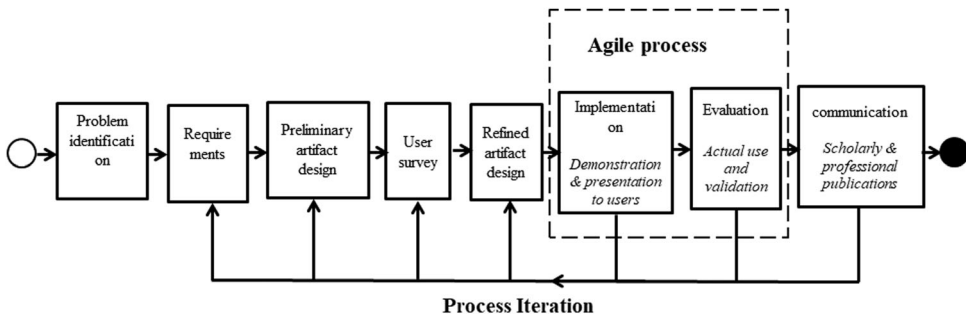


**Figure 1.** A conceptual model for sustainable agriculture in Tanzania.

services and, in some cases, their absence and the target for a future comprehensive digital solution for smallholder farmers in Tanzania.

### 3. Research method

We followed the design science research (DSR) method in this study. According to Hevner et al. (2004), the DSR method is used to design digital artifacts solutions that interact with the problem context and facilitate the development of an effective and efficient information system. We customized the DSR method process by Peffers et al. (2007) from six to eight steps: problem identification, requirements, preliminary artifact design, user survey, refined artifact design, implementation, evaluation, and communication. According to the DSR method, problem identification comes first so that subsequent processes can focus on the development of the artifact solution. The problem identification can emerge from the existing literature (problem-oriented initiation), the users' needs (context/user initiation), or from a desire to achieve a particular objective (objective-centered solution) (Peffers et al., 2007; Siemon, 2022). The second step is collecting the requirements or defining the objectives necessary for solving the identified problem. A third step is about designing preliminary artifact based on the requirements of the previous step. The fourth step is conducting a user survey which involves orienting potential users with solution design and understanding user context related to the problem, thereby getting useful feedback to improve the initial design leading to a participatory design (Hartson & Pyla, 2019). Since this study is a problem-oriented initiation, we added a 'user survey' step between artifact design and implementation to get the stakeholders' feedback (user or context initiation) for possible improvements of the original artifact design for an effective and efficient information system. The fifth step is to refine the artifact design based on the identified stakeholders needs and opinions. The sixth step is pilot implementation, which involves presentation and demonstration of a part or all of the artifact solution to potential users. This step is crucial for artifacts development; designers and developers can leverage user feedback to improve the design through process iteration. The seventh step is an evaluation by



**Figure 2.** A DSR method used in this study, inspired by Peffers et al. (2007).

implementing an artifact solution to a problem, and consists of monitoring the effectiveness and efficiency of the system; thus, feedback can be used to iterate back to the system design. The eighth step is communication, documenting the system through scholarly and professional publications (Peffers et al., 2007). Figure 2 highlights the instantiation of the DSR for our research, with the seventh step revisiting all previous steps to allow for an empirical refinement approach in the design of the artifact solution (Hevner et al., 2004).

Heeks (2016) argued that IT development can be seen as socio-technical systems where IT and society interact by shaping each other. In addition to the survey (fourth step) that gives stakeholders (society) a chance to participate in the design of the artifact, the agile methodology allows the stakeholders to intervene in the redesigning of the system during its development. The agile methodology starts from the planning to the development phases with short spans of iterative and incremental interactions of stakeholders over the process and tools throughout the project's lifecycle (Al-Saqqa et al., 2020). This practice allows changes to be made during development without jeopardizing the process or having to restart from scratch.

We first identified the problem of smallholder farmers through a systematic review of scholarly articles and gray literature (Mushi et al., 2022), followed by the conceptual design and actual artifact design. We conducted two forms of literature searches: in Web of Science (WoS), IEEE Xplore, and in related databases (FAO, Google Scholar, and Research4Life) to identify existing digital technologies used in the agriculture sector globally. Except for the Tanzanian agriculture sector, to obtain a detailed technological context, we limited the search to six years, from 2015 to 2021, to find the most recent development in digital technologies. We then evaluated their availability to smallholder farmers and sustainability in the agricultural context. We searched local repositories (Sokoine University of Agriculture), WoS, and Google Scholar to identify common challenges for smallholder farmers and selected and analyzed recent publications of digital artifacts solutions developed to solve smallholder farmers' challenges.

Requirements for the preliminary design of the FDIS artifact emerge from this existing literature. The artifact takes smallholders' challenges as requirements and develops the means necessary to mitigate the challenges toward sustainable services for smallholder farmers, including common services such as advisory services, markets, subsidies, quality farm input, and financial services. We mapped these requirements into three groups: (1) resources and ICT sustainability, (2) economic requirements and (3) environmental sustainability requirements.

#### 4. Results – artifact design and description

The FDIS data management system for smallholder farmers' services consists of stakeholders who play different roles in a complete farming cycle. Based on the conceptual model presented in Figure 2, the FDIS platform will comprise five modules: (1) farmers' data, (2) agro-dealers data, (3) farm input data, (4) advisory and (5) market services (see full description in sub-sections below).

The platform is purely driven by data from farmers and involves stakeholders such as agro-dealers and financial institutions. Therefore, after setting up the digital infrastructure, the first activity is to collect data that different actors can access and provide different services to farmers. We propose that the FDIS be managed by the government or by a public-private partnership because of the important role the government can play in networking the agricultural sector by combining various services under one roof (Rao, 2004; United States Department of Agriculture, 2002). Therefore, government-led implementation of the system should result in more sustainable agriculture – economic sustainability, environmental sustainability, and sustainability of the ICTs infrastructure and resources (Mushi et al., 2022).

#### **4.1 Farmers' data module**

The FDIS data management system for smallholder farmers should consist of comprehensive data for government, donors, investors, and other stakeholders enabled services. Like farmer profiling (Boyera & Grewal, 2020; Gray et al., 2018), the platform should include personal data that uniquely identifies a farmer, including the national identification number. Personal information should consist of elements essential to the services, such as literacy level, income, language, level of control of the farm, and details of farmer communication to find out their preferred channel of information dissemination, mainly regarding advisory services. Location information of the farmer is also critical for subsidies, tailored insurance, and credit services. Important location details include an administrative address from regional or township, district, ward, division, village, street to plot number, and Global Positioning System (GPS) coordinates. An Application Programming Interfaces (APIs) could be used to connect and verify individual farmers' identities in the national schemes of personal identification, such as the National Identification Authority (NIDA) in Tanzania. Blockchain technology is also essential to immutably record uniform and portable personal data (Gray et al., 2018). Therefore, farmers could share their data with stakeholders they wish, such as financial institutions for a service.

In addition, stakeholders need farm information to determine actual needs and provide specific support to farmers. Farm details include GPS coordinates, crop type, farm registration details, farm labor, and equipment for farming activities. According to Boyera and Grewal (2020), sometimes farmers manage several fields in different places or one piece of land divided into sections for different crops. In this case, land information such as location, size, ownership, crop and soil information is useful to support smallholder farmers. Linked to a field, production information that includes planting details, pests, and diseases with their treatments helps prepare post-harvest activities.

Most farms in Africa are uninsured; only approximately 650,000 farmers have access to insurance out of more than 40 million smallholder farmers in sub-Saharan Africa alone (Hazell & Hess, 2017), which is less than 2%. Nonetheless, financial instrument information available to farmers, including credit, subsidies, insurance, mobile money, and bank accounts, is vital for financial services. Credit information enables smallholder farmers to access credit services in line with financial instruments. Credit information includes credit history, farm production plans, and membership in micro-finance institutions. Moreover, insurance information allows other stakeholders to understand the scope of coverage, the level of production risks covered, the type of insurance company, the recurring costs, and the amount payable to farmers if the insured risk occurs. The platform offers the opportunity to improve or adopt index-based farm insurance, which scientists and organizations consider particularly effective (Hazell & Hess, 2017). These digital artifacts could potentially influence investments in insurance companies that support smallholder farmers in times of crisis.

Agricultural knowledge and farmer training, mainly through farmers' cooperatives, will enable smallholders to participate in modern farming by learning best practices in investment and management of production resources, thereby increasing production and income. Therefore, information on the qualification of the farmers constitutes an essential dataset that has implications for the value of the farm products, which is critical to marketing. Certification and training must be registered at different levels, such as farm preparations, planting, pesticide and herbicide use, irrigation, and

other farm management activities, including harvesting. In addition to the marketing segment, business information, namely agribusiness linkages, cooperative membership, market-related to the farmer, quantity harvested and sold (at the farm, cooperatives), and price sold, plays a significant role in connecting farmers to the market (Gray et al., 2018). Data about farmers should be as complete as possible to allow quality and tailored services such as subsidies distribution, advisory services, credit, and insurance (Prause et al., 2021). Here we present the conceptual solution to the farmers' problems identified in the literature (Table 1). These identified problems are not the only ones that the information system will address, and we are in the process of conducting a user survey that may highlight additional needs, based on which we will refine the design of the artifact. This survey should also allow us to assess the validity of our model's hypotheses, which are based on case studies (presented in Section 5). Therefore, a concrete design of the FDIS will address the issue identified in Table 1 and other issues that may arise from stakeholder opinions. Table 1 summarizes the essential dataset categories and problem solutions for smallholder farmer services in a complete farming cycle.

#### **4.2 Agro-dealers' data module**

Agro-dealers play an essential role in the distribution of farm inputs and enable smallholder farmers to adopt new technologies in agriculture throughout the country. However, a study by Rutsaert et al. (2021) on the geographical distribution of agro-dealers in Tanzania shows that most smallholder farmers in rural areas use very few modern farm inputs due to the lack of agro-dealers services. The few agro-dealers in remote regions face high demand and less competition, allowing them to charge higher prices to smallholders and have fewer product choices in stock (Rutsaert et al., 2021). Furthermore, some agro-dealers and their products are not certified by the authorities, resulting in the distribution of substandard inputs (Kahwili, 2020), which results in low production, poor quality products, and a negative impact on the environment and consumer health. Most smallholder farmers in Tanzania do not use industrial fertilizers (Elliot, 2016); thus, they depend on organic manure and natural land nutrients, decreasing soil fertility and crop production in the short term. As a result, smallholder farmers engage in deforestation to find new arable land, which has a negative impact on the environment and contributes to global climate change.

Agro-dealers' data module will enable policymakers, government authorities, and investors to better understand the distribution networks of agro-dealers across the country and improve the current situation toward sustainable agriculture among smallholders. By analyzing farmer data and the distribution of agro-dealers, investors can identify opportunities, especially in remote areas, allowing farmers to have a wide choice of stoked farm inputs products at a fair price. Smallholder farmers will also be able to identify certified agro-dealers and farm inputs to combat substandard inputs from uncertified dealers. Agro-dealers' data should include business name, administrative address, registration details, location with GPS coordinates, certification, and a list of services such as delivery and advisory services to farmers.

#### **4.3 Farm inputs data**

Domestically produced or imported agricultural inputs must undergo quality controls and verification before being distributed. Like many African countries after independence, the importation and distribution of farm inputs were centrally controlled by state organizations in Tanzania. Until the 1970s, the government had the Tanzania Seed Company for seeds and the state monopoly of fertilizer distribution at a subsidized price under the 1967 Arusha Declaration. However, the state then faced a debt crisis, delays, and shortages in input distribution and allowed the private sector to enter the market (Elliot, 2016). Many private sectors are involved in importing and distributing farm inputs registered and certified by government authorities. Despite the involvement of the private sector, only about 15% of the seeds planted are registered and approved by the responsible authorities, and about 2,500

**Table 1.** Farmers data and services for sustainable agriculture.

Problem description	Data categories (Boyera & Grewal, 2020; Gray et al., 2018)	Data type (Boyera & Grewal, 2020; Gray et al., 2018)	Issues to address
Poor decision, cheating and fraud in selecting and distributing subsidies to smallholder farmers (Masinjila & Lewis, 2018)	Personal information	Full names, identity numbers, gender, family details (marital status, size, family leader gender), land size and ownership status, income level, education level, other source of income	<ul style="list-style-type: none"> <li>• Transparency in selecting and allocating subsidies</li> <li>• Increase trust of other stakeholders e.g. financial institutions</li> </ul>
Existing advisory and extension services are too general for farmers to comprehend and practice	Communication Information	Language preferences, preferred channel of communication, phone details (number, smart/basic phone, phone literacy), preferred type of information (market, crop)	<ul style="list-style-type: none"> <li>• Tailored advisory and extension services</li> <li>• Right information to right farmers through a right channel</li> </ul>
Distance between farmers and service providers e.g. input traders is a challenge (Rutsaert et al., 2021)	Location details	Current and permanent physical addresses: regional/district/ward/division/plot and GPS coordinates	<ul style="list-style-type: none"> <li>• Inputs delivery services and new agro-dealers investments in demand areas</li> <li>• Useful data by other stakeholders</li> </ul>
Inability of services providers to assess farmers' production risks and opportunities	Farm data Field data	Farm registration, employee/labor, farm tools, crop type(s)/variety Field location, soil, size, land title, GPS coordinates, and crop history	<ul style="list-style-type: none"> <li>• Tailored advisory services such as inputs, credit and market services</li> <li>• Insurance services covering risks linked to field location and crop type</li> </ul>
Poor access to financial (credit and insurance) services (Kimaro, 2020; Sanka & Nkijijiwa, 2021; Simbakalia, 2012)	Financial instrument Credit Information Insurance data	Mobile money and bank accounts; accessed credit, insurance and subsidies Credit history, business plan, cooperative societies membership, active credit (loan size and use) Insured field, insurance cost, risks covered, insurance company, amount repaid if the risk(s) occurs	<ul style="list-style-type: none"> <li>• Provide payable loans and financial advisory services</li> <li>• Help farmers to create good farm business plans</li> <li>• Identify uncovered risks</li> <li>• Useful for credit services (de-risking loans)</li> </ul>
Agricultural knowledge of smallholder farmers is unknown; thus, it is difficult to determine their service packages	Qualification and certification data	Training and certification dates in different levels and stages of farming, Training/certification institutions Certificates of adhering to farming standards	<ul style="list-style-type: none"> <li>• Access unique market such as organic food products</li> <li>• Advisory service based on the knowledge gap</li> <li>• Identify needs and provide training in anticipation</li> <li>• Increase quality of products and environment</li> </ul>
Smallholder farmers do not record production information, making it difficult to prepare post-harvest activities	Production data	Planting data (amount of seeds, date, spacing, tools used, intercropping) Input data (irrigation, herbicides, fertilizer, pesticides) Pest and diseases attacks, rainfall, yield, loss and storage	<ul style="list-style-type: none"> <li>• Yield prediction and post-harvest activities preparations e.g. storage and market</li> <li>• Real-time advisory and information services to farmers</li> <li>• Early warning services</li> </ul>

(Continued)

**Table 1.** Continued.

Problem description	Data categories (Boyera & Grewal, 2020; Gray et al., 2018)	Data type (Boyera & Grewal, 2020; Gray et al., 2018)	Issues to address
Poor access to market and middlemen market disruption (Misaki et al., 2016; Navuri, 2018)	Business information	Agribusiness linkages, market expected by the farmer, price, total product sold (at farm, market, cooperate), cooperative membership	<ul style="list-style-type: none"> <li>• Predict different market that farmers can use</li> <li>• Enable farmer to connect with the market and ensure transparency of transactions</li> </ul>

Source: Author's compilation.

tons of agrochemicals were registered in Tanzania in the mid-2000s (Elliot, 2016). Studies suggest that informal farm inputs smuggled across neighboring countries dominate the market.

Moreover, most of the pesticides and seeds in Tanzania are forged in different ways, such as reprinting product labels, diluting chemicals, and copying package shapes. For these reasons, Tanzania has had a low yield per hectare compared to other developing countries. For example, the average yield of maize is 1.5 tons per hectare, while the World Bank estimates 6–7 tons when farmers use adequate and quality inputs (World Bank, 2012).

Publishing and sharing data of the registered and certified farm inputs would solve the problem of substandard farm inputs distribution. Essential data about farm input include the manufacture details, international registration details, importing or supplying agent information, registration and certification data by Tanzania authorities, usage data, and unique verification code. Therefore, farmers will be able to identify the registered agents or suppliers and verify the originality of the farm inputs such as seeds, fertilizers, and agrochemicals. The effort also requires a campaign to sensitize farmers to use quality farm inputs and their benefits.

#### 4.4 Advisory service module

The lack of comprehensive advisory service is the cause of the low adaptation of modern farming techniques by most smallholder farmers (Jack & Tobias, 2017). The Tanzania government employs outreach officers to disseminate information and advice farmers on modern farming, including farm inputs, to solve the problem. The Tanzania Agriculture and Livestock policy, revised in 2000, defines the outreach service as a transfer of agricultural technology from experts to farmers, livestock keepers, and other stakeholders (United Republic of Tanzania, 1997). However, outreach officers are limited by the number of farmers they can visit; thus, most smallholder farmers rely on traditional farming knowledge from other farmers and family members. In addition to the farmers' advisory information system developed and implemented by Sanga et al. (2013), the FDIS can provide more tailored advice from experts based on farmers' data such as location, type of soil, crop, farm equipment, and more. Agricultural Research Institutions (ARIs), through information and outreach services sections such as the Sokoine National Agricultural Library (SNAL), provide outreach information services to farmers across the country (Mushi & Egbukole, 2021). Therefore, ARIs could use farmers' digital information systems to repackage information based on the needs, literacy level, crop or livestock, and other farmers' attributes for effective advisory and outreach services to smallholder farmers (see Figure 3).

#### 4.5 Market service module

The farm product market is the core of agribusiness success and economic sustainability. The FDIS for farmers will provide market data such as different markets and product prices. This information is essential for smallholder farmers to find the right market for their products and thus earn a deserved income. Furthermore, the platform will allow farmers to publish their yield information and meet

directly with potential buyers without the intervention of intermediaries in the value chain (Figure 3). Thus, farmers will have many market options through cooperatives, trade channels, and on-farm sales fed by market price information.

### 5. Illustration with four Tanzanian case studies

The general research question regarding the feasibility and impact of FDIS at the farmer level cannot be answered directly. This is akin to modeling complex ICT for development problems, in which a theoretical framework must be supported by case studies that provide a context in which that theory will be reconciled (Samoilenko & Osei-Bryson, 2021). For this reason, we focus on lower-level research questions supported by our theoretical model represented by the identification of four common challenge cases in Tanzania that illustrate how the design of the FDIS interacts with and solves farmers' problems in distributing subsidies, accessing financial services, avoiding low-quality farm inputs, and accessing the market without involving intermediaries in the value chain. To ensure adoption and validation of the service by the various stakeholders it is important to correctly understand their needs. To this end, we are conducting interviews with different FDIS stakeholders (farmers and livestock keepers, agro-dealers, insurances companies, financial institutions, ministry of agriculture, government subsidy office, and customers). On the basis of the gathered information, we will then refine our artifact design and later implement FDIS, regularly validating our model with the stakeholders as depicted by the feedback loops in Figure 2.

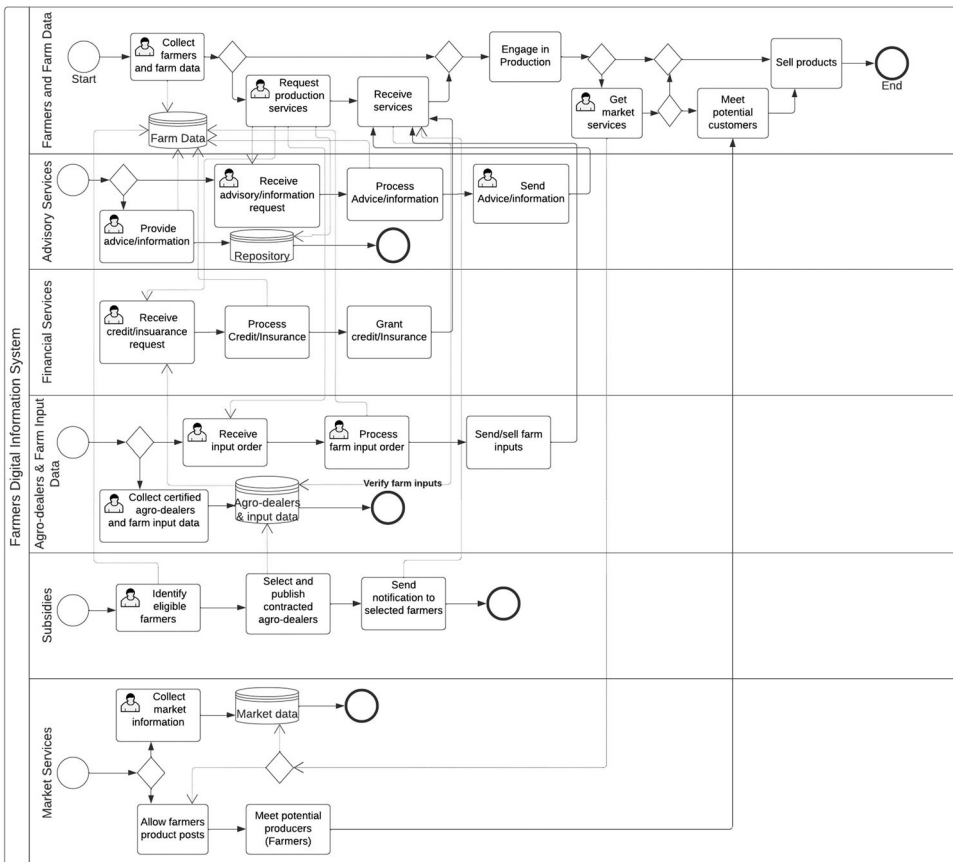


Figure 3. FDIS and farmers access to services BPMN diagram.

### 5.1 Case 1: subsidies

The Tanzania government has supported smallholder farmers through subsidies since independence. From the 1960s to the early 1970s, the government monopolized the agro-inputs market and controlled importation and distribution at a subsidized cost to enable smallholder farmers to increase production and income. Later, in the mid-1970s, the government faced a colossal debt crisis, delays in input delivery, and a shortage of these products, which allowed the private sector to enter the market (Elliot, 2016). Nevertheless, the government maintained the subsidies programs for smallholder farmers through contracts with private suppliers. Since its independence, Tanzania has had 16 National Agriculture Input Voucher Systems (NAIVS) contracts between government and input suppliers (Masinjila & Lewis, 2018). The agreements require suppliers to sell inputs such as seeds, fertilizers, and agrochemicals at a half-market price to selected smallholder farmers. The study on the effectiveness of the NAIVS suggests that the programs had a low impact on smallholder farmers due to cheating and fraud (Masinjila & Lewis, 2018). The subsidies did not reach the targeted farmers because of biases in the selection process, contracted agro-dealers denying to be part of the program and therefore selling inputs at a full-market price to subsidized farmers. For this reason, the majority of smallholder farmers do not use quality farm inputs, resulting in low production and income.

The FDIS data management system for smallholder farmers has the potential to solve the fraud and cheating in the distribution of subsidies. Data about farmers and agro-dealers is essential for transparency in selecting smallholder farmers and access to farm inputs from contracted suppliers at a half market price or any other agreement conditions. Suppose the subsidy coordination office uses the FDIS to select smallholder farmers. Then it will be possible to allocate subsidies to them based on specific criteria and send them notifications with a list of contracted agro-dealers from whom they can purchase subsidized farm inputs. The FDIS could provide data on selection criteria such as women-headed families, low-income families, farm size, and land ownership to facilitate the selection of appropriate smallholders. At the same time, farmers will be able to directly identify contracted suppliers. As a result, the targeted smallholders will be more likely to adopt the new technologies, thereby increasing their productivity and income (see Figure 3). The system could ultimately improve the impact of NAIVS programs in Tanzania and reduce extreme poverty and food insecurity among a growing population.

### 5.2 Case 2: Substandard farm inputs

After the liberalization of the input market, the government formed agencies for different input quality verification and registration for local and imported farm inputs, such as, the Tanzania Fertilizer Regulatory Authority (TFRA) for fertilizers, the Ministry of Agriculture, Food Security and Cooperatives – seed unit (MAFSC-Seed Unit), the Tanzania Official Seed Certification Institute (TOSCI) for seeds, the Tropical Pesticides Research Institute (TPRI), and the Tanzania Atomic Energy Commission (TAEC) for agrochemicals verification and registration (Elliot, 2016). These agencies aim to guarantee the quality of inputs for increased production and preservation of the environment. The quality of farm inputs is among the factors contributing to increased production and income so that farmers can get a return on their investment. However, studies show that 85% of seeds planted in Tanzania are not registered, and the input market, mainly agrochemicals, is dominated by products smuggled from neighboring countries (Elliot, 2016). Regular operations by government authorities in agro-dealers stores uncover substandard inputs that contribute to low production and high risks to human health and the environment. For instance, 'less than a quarter of agro-dealers are checked each year, and the amount of counterfeit seed circulating in the market is estimated to account for at least 25–35% of all commercial seed' (Elliot, 2016, p. 13).

On the FDIS platforms, data on inputs registered and verified by regulatory authorities will be published to allow farmers to access inputs from the registered agro-dealers. Imagine a farmer

using the FDIS on a smartphone, tablet or computer to search for verified quality of farm inputs: they will be able to find the nearby registered agro-dealers and verify the inputs through a FDIS platform, as shown in [Figure 3](#). The platform could include a digital verification for incoming products, such as a barcode or quick response code for easy verification. Such a practice will also enable the automatic removal of unregistered products and agro-dealers from the market.

### **5.3 Case 3: Financial services**

Smallholder farmers have limited access to credit and insurance services (Sanka & Nkijijiwa, 2021), which hinders the uptake of quality farm inputs and modern farm equipment to increase production. However, agricultural financing has a potential role in sustainable agriculture among smallholder farmers globally. Tanzania has experienced low agriculture production in the long term despite its abundant arable land and favorable climatic condition. Many studies link low production to lack of access to credit services; most poor farmers cannot adopt new technologies and farm inputs to increase production (Elliot, 2016). The majority of smallholder farmers, especially in rural areas, depend on cooperative institutions as a source of credit. Cooperative institutions are formed locally and loans are only granted to known members of the association who provide micro-savings as collateral for the loan (Sanka & Nkijijiwa, 2021). However, loans from cooperative institutions are limited based on members' micro-saving, limiting the farmers' ability to invest in agriculture. A study on access to credit in Tanzania shows that only 1% of total bank lending goes to the agriculture sector. The banking industry in Tanzania anticipates high risks of lending to smallholder farmers (Simbakalia, 2012). Most farms are uninsured due to farmers' financial illiteracy, low willingness to pay, and lack of trust in insurance providers (Osumba et al., 2020).

A data management system for smallholder farmers is essential for access to financial services in Tanzania. Credit services could enable farmers to adopt modern farm equipment and quality inputs for increased production and income. Farmers' data can be shared with financial institutions through APIs. For instance, a farmer using the FDIS platform could apply for a financial service, the financial institution could ask the farmer to share his/her information for evaluation purpose. Comprehensive data on farmers, farms, production, insurance, credit history, and business information can reduce the banking industry's risks in lending to farmers. The information would enable financial institutions to analyze the highest loan amount for a farmer, the ability to pay, and recovery measures if they fail to pay the loan. Likewise, insurance companies can use a similar method to offer insurance services for smallholder farmers. Index-based agriculture insurance, which seems promising for smallholder farmers (Hazell & Hess, 2017), requires farmers and field data to analyze potential risks of farmers that need to be insured. Access to credit and insurance will increase smallholder farmers' confidence, and investment in agriculture hence fostering economic development, increased production, and increased employment, especially for most unemployed youth in urban areas, reducing poverty and food insecurity.

### **5.4 Case 4: Market access**

Market access has been a critical challenge to most smallholder farmers in developing countries, including Tanzania. Lack of market information is the bottleneck of the smallholder farmers toward participating in agribusiness. Middlemen take advantage of farmers' lack of market information by buying at a low price, usually on the farm, and selling the product at a high cost to the consumers (Oguoma et al., 2011). It is heart-breaking: a report from Tanzania mentions that many farmers aim to produce mainly for (low) consumption because of regular losses in the market when they want high production for their business (Navuri, 2018). Most smallholder farmers practice subsistence agriculture; they avoid taking risks for higher production that could help increase their income, solve the country's malnutrition problems, and make the agriculture sector more dynamic.

The use of the Internet and Information Technology (IIT) has a significant impact on selecting productive sales and marketing channels, increasing farmers' income (Zhang et al., 2021). The market module of the FDIS framework will provide updated information on different markets and product prices. This information is vital to farmers when bargaining to sell their products to aggregators, consumers, agro-food processors, and other stakeholders in the market value chain. A farmer with an FDIS platform on his/her smartphone, computer, tablet, or other device could access the market price of all products (the farmer can use information to decide on future crops to plant, livestock, or post-harvest planning), use the virtual market for farm products by directly meeting potential buyers at a reasonable price (thus eliminating intermediaries in the market value chain), resulting in an incentive for increased production and income for smallholder farmers.

## 6. Discussion

The FDIS platform has the potential to reduce risk for farmers and stakeholders involved in agriculture – promising increased productivity and income, reducing inequality by empowering women in agribusiness, stimulating economic development, and solving the world's pressing challenge of producing enough nutritious food for a rapidly growing population. The digitization of the national agriculture system has the potential to empower the majority of smallholder farmers through the services provided by stakeholders in a full farming cycle. We propose a public or public-private managed digital system for the potential role of government in mobilizing the stakeholders and resources needed to empower smallholder farmers for sustainable agriculture.

### 6.1 An FDIS toward sustainable agriculture

Smallholder farmers could achieve sustainability in the agriculture context – economic sustainability, environmental sustainability, ICTs infrastructure, and resources sustainability, as smallholder farmers have access to financial (credit and insurance) and tailored advisory services that would enable them to invest in modern farming techniques, improved farm equipment, and quality inputs, resulting in increased production (Mushi et al., 2022). Furthermore, an FDIS could increase profitability by facilitating access to market information and linking smallholder farmers with potential customers. Therefore, an FDIS can help smallholder farmers to achieve economic sustainability – increased production and income. An FDIS can play a role in environmental sustainability through ecological conservation and reducing the impact of ICT on the environment. The ability of smallholders to identify certified and registered farm inputs, particularly agrochemicals and fertilizer, could eventually lead to the elimination of counterfeit products that could harm the ecology and health of consumers. Moreover, increased uptake of quality inputs such as fertilizers at a required amount would make the cultivated area productive for the long term, avoiding deforestation in seeking new arable land. FAO report that cultivated area will increase by 12% in developing countries, particularly in Sub-Saharan Africa and Latin America, while decreasing by eight percent (8%) in developed countries by 2050 (FAO, 2009).

It should be noted that the FDIS platforms also contribute to environmental pollution mainly through carbon emissions in data centers. Therefore, to reduce the environmental impact of ICT, portable devices (for data collection and service access) such as smartphones and tablets are encouraged, as they are energy efficient (Jindal et al., 2012). We propose using the green fog computing model to implement the FDIS architecture to diminish carbon emissions and high energy consumption in centralized data centers (Qureshi et al., 2021). In the hierarchal arrangement of fog nodes, small data centers in each region will act as a fog with the ability to use renewable energy sources such as wind and solar power, thus less carbon emissions and energy consumption, which is promising for environmental sustainability. FDIS platforms use ICT infrastructures, which require financial and human resources to manage in order to provide long-term digital services to smallholder farmers. Those infrastructures require regular maintenance, hardware and software

upgrades, and qualified staff to ensure the daily operation of the system. In addition, collecting and updating data requires human intervention to ensure data quality. An FDIS as a public or public-private managed platform will operate under public office, thus, receiving financial and human resources from the government. To fund the FDIS, the government can generate revenue by charging stakeholders such as financial institutions, agro-dealers, and the market to support ICTs infrastructure and resources sustainability. An FDIS as a public-managed platform would be more services-oriented than a profit-based business model. Therefore, the fee should be as low as possible, which should not affect the income of smallholder farmers.

## **6.2 Toward an implementation of an FDIS**

### **6.2.1 Infrastructure and resources for FDIS sustainability**

Several factors surround ICT projects to ensure their successful implementation and sustainable operation. While a critical enabler, investment in ICT infrastructure alone cannot produce the desired socio-economic impact (Bollou & Ngwenyama, 2010). Therefore, complementary investments such as good policy, an education system, stable electricity service, a skilled workforce, and other resources are essential for the sustainability and maximum impact of ICT projects (Ngwenyama & Morawczynski, 2010).

The proposed FDIS is an ICT project that aims to have a socio-economic impact at the national level by enabling smallholder farmers to access essential services that maximize their production and income. The envisaged system requires investment in ICT infrastructures such as communication networks, data centers, Internet services, ICT devices and other related tools, which drive the impact (Samoilenko & Osei-Bryson, 2021). Samoilenko and Osei-Bryson (2021) added that these drivers attract activities, investments, and resources such as a skilled workforce, electric service, and sound policy for successful and sustainable operations for the desired socio-economic implications. Current investment in ICT infrastructure, particularly wireless communication (Sinda, 2021), rural electrification (Bensch et al., 2019), and rural farmers increasing mobile usage and Internet access (Msoffe & Lwoga, 2019) in Tanzania are promising drivers for the implementation and sustainable operation of the FDIS framework. In addition, the national education system fosters the availability of a skilled workforce such as ICT specialists, data management experts, logistics personnel, and many other human resources needed to make a maximum socio-economic impact for the country. ICT in support of the country's agriculture development policy is also critical to the planned implementation of the FDIS, stakeholder adoption and sustainability of the platform. For instance, an ICT policy to digitize the national agricultural system could rally all stakeholders, identify new areas of skill development, logistics, and food supply chain development, and other events necessary to achieve the desired economic outcome.

FDIS as a disembodied digital artifact solution – which runs on computers, smartphones, tablets and similar devices and is not tied to specific livestock, crops, or farm equipment (Birner et al., 2021), would require access to public data such as spatial and non-spatial agricultural information to function. Although lagging behind, some governments in low- and middle income countries are beginning to provide public data to support the agriculture sector. For instance, the 'AGIS Comprehensive Atlas' in South Africa provides a wide range of spatial data services, including land use, soil quality, crops and vegetation, climate change, national agricultural infrastructure, and others (Open Data South Africa, 2022). Public data plays an important role in agriculture, including supporting farm advisory services, planning, crop management, post-harvest activities, investments, pest and disease control, and agriculture research, to name a few.

### **6.2.2 Leveraging available infrastructure and resources**

There are some existing services that we can adapt to the FDIS platform without developing them from scratch. A study should be conducted to identify the current services to be included in an FDIS. For instance, electronic data on registered and certified farm inputs published by responsible

government authorities (Elliot, 2016) and advisory information systems (Sanga et al., 2013), as well as mobile applications such as the one to combat substandard farm inputs (Shao & Edward, 2014). However, most existing services may require modifications to achieve the desired benefits to smallholder farmers. An FDIS would also need data exchange mechanisms such as linking to a national identification system to collect farmers' identities and exchanging data via APIs with services providers, primarily financial institutions. Data collection for FIDS is an expensive task and requires substantial financial resources during project implementation because it involves a large number of staff and equipment. Nevertheless, outreach workers across the country in Tanzania could be responsible for regularly updating data from their regions after the project's duration. Therefore, an FDIS could use minimal resources by effectively utilizing existing government human and material resources.

### **6.3 Issues related to data**

FDIS is a data-driven artifact solution for smallholder farmers. Therefore, the implementation of the solution requires prior consideration of various data-related issues. These issues include data protection, data quality, data ownership and sovereignty.

#### **6.3.1 Legal issues on data protection**

FDIS collects, stores, and shares personal data with third parties for services to smallholder farmers. Tanzania is currently drafting its personal data protection legislation (UNCTAD, 2021), which will strongly regulate data collection, storage, and sharing of such information. Until then, FDIS will require implementing a specific process aligned with the legislation. The common principle of 'purpose limitation' can be applied to protect both personal and non-personal data, that data should not be used for any other purpose than those consented by the farmers and other stakeholders (FAO, 2021). Although requirements among countries vary, the common legislation for collecting, storing, and sharing personal information requires the farmers' consent. It lets them know the purpose and the list of organizations with which the information will be shared (Boyera & Grewal, 2020). Therefore, the implementation of an FDIS will require a training and awareness campaign for smallholder farmers on the purpose and benefits of collecting, storing, and sharing their data with other stakeholders. Farmers will also need to sign consent forms to allow the sharing of information with stakeholders providing the necessary services in a complete farming cycle.

#### **6.3.2 Data ownership and sovereignty**

Data sovereignty is a rich and multi-dimensional concept, but it is usually tied in some way to control of the data life-cycle, i.e. collection, storage, access, use and reuse, including deletion (Hummel et al., 2021). Data sovereignty also raises concerns about government authority over data hosted in foreign clouds, as it depends on the laws of the country in which the data is located (Irion, 2012). Moreover, the introduction of data management model solutions in agriculture poses new data sovereignty challenges, as agricultural technology providers can take control of the data collected (Prause et al., 2021). Consequently, the question arises who owns the data between the farmers, the companies, or the organizations that manage the digital platform? The simple answer is that farmers own the data, sometimes mentioned in the contracts; however, this may not be addressed in them (FAO, 2021). The complexity of data ownership and legislation is due to its non-tangible nature compared to other objects. FAO (2021) mentions that legally, data is not exhaustible: it can be copied, transferred, and migrated, and the same data can be in different locations and owned by different people. As an ad hoc solution, the FDIS platform could adopt existing legal and regulatory frameworks dealing with data ownership (Townsend et al., 2019), as future legislation could resolve some issues around data ownership. Similar to a digital farmer profiling platform (Boyera et al., 2017; Gray et al., 2018), an FDIS collects data that can be 'captured' – leveraging the data collected from the users of the platform for commercial purposes, potentially selling the data to investors,

advertisers, product or service innovators (Fraser, 2019). Schrijver (2016) mentioned that giving farmers control over their data flow to other stakeholders builds trust with farmers for data exchange and benefits services for sustainable agriculture. Therefore, farmers and stakeholders should have ownership and control rights, such as deciding on the sharing of data for other purposes and its reuse to prevent agricultural technology providers from taking it. Indeed, farmers should control and decide on the data generated by their actions to benefit all partners involved and not fall victim to a 'data grab' that only benefits agricultural technology providers (Fraser, 2019; Prause et al., 2021). For instance, through an open data charter that would enable the design of open repositories for farm data, farmers could share some or all of their data, such as the sharing of data from a particular farm or crop with a partner to facilitate planting, chemical or fertilizer application, post-harvest services, etc. (Puri, 2016; Fraser, 2019; Prause et al., 2021). In addition, an FDIS requires a legal and regulatory framework that grants 'data owners' the right to delete their data and opt out of the platform completely, thereby ensuring ownership and protection of farmers' data, which, without stricter rules, is currently being allowed to be taken over by agricultural technology providers (Prause et al., 2021). Increased public and private sector investment in ICT infrastructure in Tanzania (Sinda, 2021) could attract domestic hosting of the FDIS framework to achieve data sovereignty. However, foreign clouds could also be helpful with a high encryption mechanism to protect data from unauthorized access and use (Winandy, 2011).

### **6.3.3 Data quality**

Data quality is essential for the FDIS to effectively and efficiently provide services to the farmers and stakeholders involved in a complete farming cycle. In this regard, data quality refers to the completeness, timeliness, accuracy, consistency, and precision of the data. The FDIS will collect and capture static (i.e. personal information) and dynamic data that require regular updates, such as crop status and production information. FDIS could use APIs to connect and verify farmer identities in national personal identification systems to ensure consistency in individual farmer data. As an incentive, it is essential to train farmers and other stakeholders on the importance of updating their data and the quality issues, not just that of provider services. Autonomous data collection, such as sensors and unmanned ground and air vehicles (UGV and AV), could ensure data quality; however, these tools require a huge upfront investment (Daum et al., 2021). In general, the manual tasks of data collection and update could involve well-trained staff, including extension agents, in collaboration with farmers and other stakeholders. Indeed, as part of the data quality control process, FDIS will apply verification and validation procedures to ensure data validity and reliability.

### **6.4 FDIS and smallholder farmers' empowerment**

Smallholder farmers will mainly access the FDIS platform through mobile phones. The increased penetration of inexpensive mobile phones (prices consistently decreasing) and access to Internet in rural areas (Silver & Johnson, 2018), create opportunities for empowering smallholder farmers globally. A recent report on the digitization of African agriculture indicates that around 33 million smallholders were using digital apps in 2019. This number is expected to grow to about 200 million smallholders by 2030 (Technical Centre for Agriculture and Rural Cooperation (CTA) 2019). Ayim et al. (2022) ascertained that text and voice-based services over mobile phones are the main ICTs adopted by smallholder farmers in Africa to improve access to accurate and timely agricultural information. Similarly, a study in Tanzania shows that mobile phones are essential tools for rural farmers in accessing information and communication, leading to various development outcomes (Msoffe & Lwoga, 2019). Therefore, integrating these services into the FDIS platform will allow farmers to access personalized information and advisory services from experts and outreach officers on-farm preparation, sowing, and recommended farm inputs for soil fertility, crop protection, and increased agricultural productivity. Also, an FDIS provides timely dissemination and access to early warning information to prevent severe crop losses; examples include weather advisories and related risks such as drought

and floods, crop diseases, and pest outbreaks. An FDIS could enable timely communication of research output and agriculture technologies from Agriculture and Research Institutions (ARIs), including the Tanzania Agricultural Research Institute (TARI), which has a network of 17 centers, and universities. The ARI's main tasks involve disseminating produced knowledge to the agrarian community across the country for farmers to adopt modern farming. ARIs, in collaboration with media (community radio) and outreach officers, can become reliable sources of information and advisory services for farmers, raising awareness and building agribusiness skills. Unlike farmers who rely on traditional sources of information such as word-of-mouth from fellow farmers, community elders, family members, and superstitious beliefs (Misaki et al., 2016). An FDIS allows ARIs, experts, and outreach officers to repack and disseminate information based on farmers' literacy level, perceived information needs, location, types of crops or livestock, and other information. These tailored information and advisory services could significantly improve modern farming practices for sustainable agriculture among smallholder farmers. Generally, farmers will be able to make informed decisions on various farming activities in a complete farming cycle.

An FDIS connects smallholder farmers with a network of service providers, namely financial institutions, agro-dealers, agronomists, donors, investors, and business and government services over various matters that empowers farmers. For instance, some donors and investors commit to empowering different levels (poor, moderately poor, and abysmal) of smallholder farmers, as in USAID's 'Feed the Future' program in Tanzania (USAID, 2021). An FDIS could provide information to identify these groups and the positive impacts on targeted smallholder farmers. Policymakers will also access vital information to understand different smallholder farmers' concerns better, thus designing and implementing policies that benefit smallholder farmers and promote agriculture and rural development.

### **6.5 IT and human development**

An FDIS is an IT-based framework solution for smallholder farmers aiming to foster economic growth in developing countries. According to Heeks (2016), digital development is a socio-technical system in which ICTs and society are interconnected and influence each another. The process involves social-technical systems that include socio-economic and political aspects that participate in the design, use and management of digital development (Heeks, 2016). The design, use and governance of the FDIS framework adhere to the principle of IT for development as it involves national-level agriculture stakeholders and digital technology for socio-economic development. An FDIS involves stakeholders from the initial stage of artifact design (user survey) through implementation and evaluation that entail the use and governance of digital development.

An FDIS has the potential to enable smallholder farmers access to financial services for investment in agriculture, achieve increased agricultural products and find reliable markets which results to increased income and social well-being of the society. The digital framework also strengthens the country's agricultural value chains as it brings together critical agricultural stakeholders, namely farmers, agro-dealers, processing industries, consumers, government, donors and investors. An FDIS promotes transparency, collaboration and inclusiveness of the marginalized groups such as rural farmers, women and indigenous communities. Policy and decision makers can access reliable information about different matters of smallholder farmers and design policies that stimulates economic development of the country.

### **6.6 Challenges of implementing FDIS framework**

Although it looks promising, the FDIS framework may face various challenges that could hinder its full potential. First and foremost, digital literacy is vital for all stakeholders involved in the farming cycle. Despite the spread of smartphones and Internet penetration (Schroeder et al., 2021), digital literacy remains a barrier to digital solutions in developing countries (Lopez & Aminu, 2021). It

can affect the adoption and use of the FDIS framework, data quality (manual entry), and the overall services provided by service providers. In addition, the digital divide between literate and illiterate people, large and small farms, women and men, and industrialized and developing countries may emerge (Birner et al., 2021). Digital literacy training for farmers and stakeholders is critical to the performance of the FDIS framework. The challenge of incentives to extension workers, farmers, agro-dealers, and other stakeholders could affect manual data entry, thereby distorting the quality of services. Therefore, raising awareness and encouraging all stakeholders to manually enter data could ensure quality of data and services to all relevant stakeholders (Daum et al., 2021). Agricultural policy directly influences the adoption of ICT as impact driver (Samoilenko & Osei-Bryson, 2021). Creating policies that encourage the digitization of the national agriculture system could lead to successful implementation of the FDIS framework. Like other digital agricultural data management solutions, FDIS may face the challenge of policy frameworks and guidelines that address data ownership, sovereignty, privacy, and security issues due to the unique nature of the data (Daum et al., 2021; FAO, 2021). The integration of different data from different sources and formats could be a setback for the FDIS framework; however, the problem can technically be addressed during implementation. In addition, limited access to public data in most developing countries (Birner et al., 2021), could affect the quality of services under FDIS frameworks. The government should consider making public data (i.e. spatial and non-spatial agricultural information) accessible for sustainable agriculture via the envisioned framework.

## 7. Conclusion

### 7.1 Digital artifact summary

We presented FDIS, a vital digital artifact for sustainable agriculture, especially for governments directly involved in decision making, regulation, and control of different aspects that affect the agriculture sector. FDIS could provide effective and transparent means for government involvement in the agricultural sector through accurate and timely information. In most developing countries, governments have considerable influence over the agricultural sector, which affects the market and distribution of inputs, stakeholder investments, and the market of agriculture products. For instance, through its agencies, the Tanzania government is involved in the importation and registration of farm inputs, subsidies programs, agriculture financing, and controls export markets of agriculture products. The government could oversee the distribution of quality farm input throughout the country and the prices of these inputs, which are high in some areas due to the cost of transportation, resulting in low adoption by farmers (Elliot, 2016). Therefore, in collaboration with input suppliers, the government could implement mitigation strategies to reduce the cost of inputs in the identified areas in order to increase the use of quality inputs and increase the productivity and income of smallholder farmers.

The FDIS operation could prompt the government to review existing flawed policies and reforms (Cooksey, 2012) to promote growth in the agriculture sector. Moreover, stakeholders and farmers could prepare local and international markets through early production estimations. Also, it is easy to identify, control and communicate early warnings about disasters and other potential risks such as pests and diseases (Cooksey, 2012). Indeed, the FDIS platforms encourage transparency in government services and control such as subsidies distribution, combating substandard inputs, and regulating input and farm products market prices.

An FDIS is an opportunity to grow and develop private sector investment in agriculture. It could eliminate unfair competition between registered and certified farm inputs and uncertified ones produced locally or smuggled from neighboring countries. The platform provides essential data for investors, such as agro-dealers services in areas with high input demand and processing industries in regions with sufficient raw materials. These improvements could attract most unemployed youth who have left agriculture and moved to urban areas in search of better income-generating jobs. An

FDIS promotes sustainable agriculture, a more active role for government and other stakeholders, and whose practical implementation can eliminate existing challenges and make agriculture a reliable sector for youth employment and food production. It further stimulates IT for human development through increased income and profitability, inclusion of underrepresented people such as rural farmers, women and other marginalized groups. Thus, it contributes to achieving zero hunger and reducing extreme poverty – the first and second Sustainable Development Goals of the United Nations.

## 7.2 Future work

This study proposes a comprehensive digital platform for sustainable agriculture among smallholder farmers. To contextualize the general model, we illustrate it from four case studies in Tanzania. We believe that a platform that pulls together key stakeholders would solve common challenges of smallholder farmers by enabling access to essential services in a complete farming cycle under one roof through a single point of entry. The next step will be to interview these stakeholders, whose responses will allow us to strengthen our model according to the loops illustrated in [Figure 2](#). The article stimulates similar research on developing digital solutions that brings together critical stakeholders for the economic, political and social development of people. The presented Business Process Modelling and Notation (BPMN) diagram ([Figure 3](#)) for different FDIS modules is the first concrete step toward developing our platform. To the best of our knowledge, this is the first artifact that focuses on a comprehensive solution to common challenges and transparency of services toward sustainable agriculture among smallholder farmers. Practitioners can play a significant role of mobilizing resources and stakeholders to achieve this digital development in agriculture sector. In future work, we plan to demonstrate part of the artifact solution and conduct a user survey in Tanzania to assess the applicability of this FDIS artifact by stakeholders for the implementation of the sustainable agriculture platform. The survey could identify missing service components and data sets for smallholder farmers and other stakeholders. This testing of our model against the harsh realities of smallholder farmers could prompt a redesign to improve the artifact.

## Notes

1. Most studies mention economic and partly environmental sustainability as the two components of sustainable agriculture. In addition, Mushi et al. (2022) consider other resources, ICTs infrastructure sustainability and green computing (environment sustainability) essential components of sustainable agriculture.
2. Although FDIS is designed for Tanzania's national agricultural system, it can be adopted in the context of any other developing country.

## Acknowledgments

This paper is part of the more extensive study supported by the ESKAS – Swiss Government Excellence Scholarship.


## Disclosure statement

No potential conflict of interest was reported by the authors.

## ORCID

Gilbert Exaud Mushi  <http://orcid.org/0000-0002-2639-9692>

Giovanna Di Marzo Serugendo  <http://orcid.org/0000-0001-5048-5251>

Pierre-Yves Burgi  <http://orcid.org/0000-0002-4956-9279>

## References

- 365FarmNet. (2022). *Digitalise your farming with 365FarmNet*. 365FarmNet. Retrieved from <https://www.365farmnet.com/en/>.
- Al-Saqqq, S., Sawalha, S., & Abdelnabi, H. (2020). Agile software development: Methodologies and trends. *International Journal of Interactive Mobile Technologies (IJIM)*, 14(11), 246–270. <https://doi.org/10.3991/ijim.v14i11.13269>
- Ayim, C., Kassahun, A., Addison, C., & Tekinerdogan, B. (2022). Adoption of ICT innovations in the agriculture sector in Africa: A review of the literature. *Agriculture & Food Security*, 11(1), 1–17. <https://doi.org/10.1186/s40066-021-00340-7>
- Behera, B. S., Das, T. K., Jishnu, K. J., Behera, R. A., Behera, A. C., & Jena, S. (2015). E-governance mediated agriculture for sustainable life in India. *Procedia Computer Science*, 48(C), 623–629. <https://doi.org/10.1016/j.procs.2015.04.144>
- Bello-Bravo, J., Abbott, E., Mocumbe, S., Maria, R., Mazur, R., & Pittendrigh, B. R. (2020). An 89% solution adoption rate at a two-year follow-up: Evaluating the effectiveness of an animated agricultural video approach. *Information Technology for Development*, 26(3), 577–590. <https://doi.org/10.1080/02681102.2019.1697632>
- Bensch, G., Cornelissen, W., Peters, J., Wagner, N., Reichert, J., & Stepanikova, V. (2019). *Electrifying rural Tanzania: A grid extension and reliability improvement intervention* (pp. 83). Ministry of Foreign Affairs.
- Bhakta, I., Phadikar, S., & Majumder, K. (2019). State-of-the-art technologies in precision agriculture: A systematic review. *Journal of the Science of Food and Agriculture*, 99(11), 4878–4888. <https://doi.org/10.1002/jsfa.9693>
- Birke, F. M., & Knierim, A. (2020). ICT for agriculture extension: Actor network theory for understanding the establishment of agricultural knowledge centers in South Wollo, Ethiopia. *Information Technology for Development*, 26(3), 591–606. <https://doi.org/10.1080/02681102.2020.1727826>
- Birner, R., Daum, T., & Pray, C. (2021). Who drives the digital revolution in agriculture? A review of supply-side trends, players and challenges. *Applied Economic Perspectives and Policy*, 43(4), 1260–1285. <https://doi.org/10.1002/aep.13145>
- Bollou, F., & Ngwenyama, O. (2010). Are ICT investments paying off in Africa? An analysis of total factor productivity in six West African countries from 1995 to 2002. *Information Technology for Development*, 14(4), 294–307. <https://doi.org/10.1002/ITDJ.20089>
- Boyera, S., Addison, C., & Msengezi, C. (2017). *Farmer profiling: Making data work for smallholder farmers*. (No. 17; 09). Retrieved from <https://cgspace.cgiar.org/handle/10568/89763> (Accessed: 5 March 2022).
- Boyera, S., & Grewal, A. (2020). *A generic template for farmer profiling*. SBC4D. Retrieved from [https://pub.sbc4d.com/2020/farmer\\_profiling.pdf](https://pub.sbc4d.com/2020/farmer_profiling.pdf).
- Chandra, R., & Collis, S. (2021). Digital agriculture for small-scale producers. *Communications of the ACM*, 64(12), 75–84. <https://doi.org/10.1145/3454008>
- Cloete, E., & Doens, M. (2008). B2B e-marketplace adoption in South African agriculture. *Information Technology for Development*, 14(3), 184–196. <https://doi.org/10.1002/itdj.20105>
- Cooksey, B. (2012). *Politics, patronage and projects: The political economy of agricultural policy in Tanzania*. In FAC Political Economy of Agricultural Policy in Africa (PEAPA) work stream (Issue March). Retrieved from [https://assets.publishing.service.gov.uk/media/57a08a86ed915d3cfd0007ee/FAC\\_Working\\_Paper\\_040.pdf](https://assets.publishing.service.gov.uk/media/57a08a86ed915d3cfd0007ee/FAC_Working_Paper_040.pdf).
- Daum, T., Ravichandran, T., Kariuki, J., Chagunda, M., & Birner, R. (2021). Connected cows and cyber chickens? Stocktaking and case studies of digital livestock tools in Kenya and India. *Agricultural Systems*, 196, 103353. <https://doi.org/10.1016/j.agsy.2021.103353>
- Elliot, A. (2016). Registering and certifying agricultural inputs in tanzania: An updated assessment of key constraints and recommendations for change tanzania sector study (Issue October).
- FAO. (2009). *Global agriculture towards 2050*. In *FAO High Level Expert Forum—How to Feed the World in 2050*. Retrieved from [https://www.fao.org/fileadmin/templates/wsfs/docs/Issues\\_papers/HLEF2050\\_Global\\_Agriculture.pdf](https://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf) (Accessed: 15 November 2021).
- FAO. (2018, June 19). *KALRO launches 14 mobile apps to transform agriculture | E-Agriculture*. Retrieved from <https://www.fao.org/e-agriculture/news/karlo-launches-14-mobile-apps-transform-agriculture>.
- FAO. (2021). *Farm data management, sharing and services for agriculture development*. FAO. <https://doi.org/10.4060/cb2840en>
- Fraser, A. (2019). Land grab/data grab: Precision agriculture and its new horizons. *The Journal of Peasant Studies*, 46(5), 893–912. <https://doi.org/10.1080/03066150.2017.1415887>
- Giray, G., & Catal, C. (2021). Design of a data management reference architecture for sustainable agriculture. *Sustainability*, 13(13), 7309. <https://doi.org/10.3390/su13137309>
- Gray, B., Babcock, L., Tobias, L., McCord, M., Herrera, A., & Cadavid, R. (2018). *Digital farmer profiles: Reimagining smallholder agriculture*. United States Agency for International Development. [https://www.usaid.gov/sites/default/files/documents/15396/Data\\_Driven\\_Agriculture\\_Farmer\\_Profile.pdf](https://www.usaid.gov/sites/default/files/documents/15396/Data_Driven_Agriculture_Farmer_Profile.pdf) (Accessed: 21 October 2021).
- Hamill, S. (2017). Strengthening agricultural market access with ICT. In World Bank (Ed.), *ICT in agriculture (updated edition): Connecting smallholders to knowledge, networks, and institutions* (pp. 225–265). The World Bank. [https://doi.org/10.1596/978-1-4648-1002-2\\_Module9](https://doi.org/10.1596/978-1-4648-1002-2_Module9)
- Hartson, R., & Pyla, P. (2019). Background: Design. In R. Hartson & P. Pyla (Eds.), *The UX book* (2nd ed., pp. 397–401). Morgan Kaufmann. <https://doi.org/10.1016/B978-0-12-805342-3.00019-9>

- Hazell, P., & Hess, U. (2017). Beyond hype : Another look at index-based agricultural insurance. In P. Pingali & G. Feder (Eds.), *Agriculture and rural development in a globalizing world* (pp. 211–226). Routledge. <https://doi.org/10.4324/9781315314051-11>
- Heeks, R. (2016). Examining 'Digital development': The shape of things to come?. In R. Heeks (Ed.), *Development informatics working paper no. 64* (pp. 1–85). Centre for Development Informatics Global Development Institute, SEED. <https://doi.org/10.2139/SSRN.3431739>
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, 28(1), 75–105. <https://doi.org/10.2307/25148625>
- Hossain, M. A., & Siddique, M. N. A. (2020). Online fertilizer recommendation system (OFRS): A step towards precision agriculture And optimized fertilizer usage By smallholder farmers In Bangladesh. *European Journal of Environment and Earth Sciences*, 1(4), 1–9. <https://doi.org/10.24018/ejgeo.2020.1.4.47>
- Hummel, P., Braun, M., Tretter, M., & Dabrock, P. (2021). Data sovereignty: A review. *Big Data and Society*, 8(1), 1–17. [https://doi.org/10.1177/2053951720982012/ASSET/IMAGES/10.1177\\_2053951720982012-IMG2.PNG](https://doi.org/10.1177/2053951720982012/ASSET/IMAGES/10.1177_2053951720982012-IMG2.PNG)
- Irion, K. (2012). Government cloud computing and national data sovereignty. *Policy & Internet*, 4(3-4), 40–71. <https://doi.org/10.1002/poi3.10>
- ITU. (2016). *ITU-T Focus discussion digital financial services. Impact of agricultural value chains on digital liquidity. International Telecommunications Union (ITU)*.
- Jack, K., & Tobias, J. (2017). *Seeding success: Increasing agricultural technology adoption through information*. Retrieved from <https://www.theigc.org/>.
- Jindal, G., Devi, R., & Gupta, M. (2012). Green computing “future of computers”. *International Journal of Emerging Research in Management & Technology*, 1(2), 14–18. <http://www.researchgate.net/publication/277138724>.
- Kahwili, R. M. (2020). *Role of Agro-Dealers in Inputs Distribution and the Counterfeit Challenges to Smallholder Farmers in Tanzania [Sokoine University of Agriculture]*. Retrieved October 21, 2021, from <http://repositorio.unan.edu.ni/2986/1/5624.pdf>.
- Kimaro, P. J. (2020). Livelihood capabilities' diversification strategies among small-scale coffee farmers in Hai and Arumeru districts, Tanzania. *East African Journal of Social and Applied Sciences*, 2(2), 167–181.
- Kinuthia, B. K., & Mabaya, E. (2017). *The impact of agricultural technology adoption on farmer welfare in Uganda and Tanzania* (Policy Brief No. 163; Partnership for Economic Policy, pp. 1–3). Africa Portal. <https://www.africaportal.org/publications/impact-agricultural-technology-adoption-farmer-welfare-uganda-and-tanzania/>
- Kirui, O. K., Okello, J. J., & Nyikal, R. (2010). Awareness and use of m-banking services in agriculture : The case of small-holder farmers in Kenya. In *Contributed Paper Presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19-23, 2010*. <http://hdl.handle.net/11295/35264>
- Krell, N. T., Giroux, S. A., Guido, Z., Hannah, C., Lopus, S. E., Caylor, K. K., & Evans, T. P. (2021). Smallholder farmers' use of mobile phone services in central Kenya. *Climate and Development*, 13(3), 215–227. <https://doi.org/10.1080/17565529.2020.1748847>
- Lopez, M., & Aminu, Z. R. (2021, March 26). *The World Bank in partnership with EQUALS launches new program to support digital skills development*. World Bank. <https://blogs.worldbank.org/digital-development/world-bank-partnership-equals-launches-new-program-support-digital-skills>
- Magesa, M. M., Michael, K., & Ko, J. (2014). Access to agricultural market information by rural farmers in Tanzania agricultural market information services in developing countries view project access to agricultural market information by rural farmers in Tanzania. *International Journal of Information and Communication Technology Research*, 4(7), 264–273.
- Maredia, M. K., Reyes, B., Ba, M. N., Dabire, C. L., Pittendrigh, B., & Bello-Bravo, J. (2018). Can mobile phone-based animated videos induce learning and technology adoption among low-literate farmers? A field experiment in Burkina Faso. *Information Technology for Development*, 24(3), 429–460. <https://doi.org/10.1080/02681102.2017.1312245>
- Masinjila, S., & Lewis, L. (2018). *The Future of Smallholder Farmer Support in Tanzania: Where to After National Agricultural Input Voucher System (NAIVS)?* (L. Sparg, ed., pp. 1–40). African Centre for Biodiversity. <https://acbio.org.za/corporate-expansion/future-smallholder-farmer-support-tanzania-after-national-agricultural-input-voucher-system/>
- Misaki, E., Apiola, M., & Gaiani, S. (2016). Technology for small scale farmers in Tanzania: A design science research approach. *The Electronic Journal of Information Systems in Developing Countries*, 74(1), 1–15. <https://doi.org/10.1002/j.1681-4835.2016.tb00538.x>
- Msoffe, G. E. P., & Lwoga, E. T. (2019). Contribution of mobile phones in expanding human capabilities in selected rural districts of Tanzania. *Global Knowledge, Memory and Communication*, 68(6/7), 491–503. <https://doi.org/10.1108/GKMC-10-2018-0084>
- Mtega, W. P. (2021). Communication channels for exchanging agricultural information among Tanzanian farmers: A meta-analysis. *IFLA Journal*, 47(4), 570–579. <https://doi.org/10.1177/03400352211023837>
- Mushi, G., & Egbukole, K. (2021). Serving the public: African academic libraries and outreach services . In C. Mnubi-Mchombu, C. Nengomasha, & W. Utoni (Eds.), *Proceedings of the 24th standing conference of eastern, central and*

- Southern African library and information associations* (pp. 248–257). National Information Workers Association of Namibia. 8–11 February 2021. [https://www.scecsal.org/publications/papers2021/scecsal\\_papers2021\\_mushi.pdf](https://www.scecsal.org/publications/papers2021/scecsal_papers2021_mushi.pdf)
- Mushi, G. E., Serugendo Di Marzo, G., & Burgi, P.-Y. (2022). Digital Technology and Services for Sustainable Agriculture in Tanzania: A Literature Review. *Sustainability*, 14(4), 2415–2417. <https://doi.org/10.3390/SU14042415>
- Namyenya, A., Daum, T., Rwamigisa, P. B., & Birner, R. (2021). E-diary: A digital tool for strengthening accountability in agricultural extension. *Information Technology for Development*, 28, 319–345. <https://doi.org/10.1080/02681102.2021.1875186>
- Navuri, A. (2018, May 14). *The farmer and the middlemen*. IPP Media. <https://www.ippmedia.com/en/news/farmer-and-middlemen>.
- Ngwenyama, O., & Morawczynski, O. (2010). Factors affecting ICT expansion in emerging economies: An analysis of ICT infrastructure expansion in five Latin American countries. *Information Technology for Development*, 15(4), 237–258. <https://doi.org/10.1002/ITDJ.20128>
- Oguoma, O., Nkwocha, V., & Ibeawuchi, I. (2011). Implications of middlemen in the supply chain of agricultural products. *Journal of Agriculture and Social Research (JASR)*, 10(2), 77–83. <https://doi.org/10.4314/jasr.v10i2.67575>
- Onyango, C. M., Nyaga, J. M., Wetterlind, J., Söderström, M., & Piiikki, K. (2021). Precision agriculture for resource use efficiency in smallholder farming systems in sub-saharan africa: A systematic review. *Sustainability (Switzerland)*, 13(3), 1158–1118. <https://doi.org/10.3390/su13031158>
- Open Data South Africa. (2022, September). *Agriculture data resources*. Open Data South Africa Toolkit. <https://opendataza.gitbook.io/toolkit/open-data-resources/agriculture-data-sources>.
- Ortiz-Crespo, B., Steinke, J., Quirós, C. F., van de Gevel, J., Daudi, H., Gaspar Mgemiloko, M., & van Etten, J. (2021). User-centred design of a digital advisory service: Enhancing public agricultural extension for sustainable intensification in Tanzania. *International Journal of Agricultural Sustainability*, 19(5–6), 566–582. <https://doi.org/10.1080/14735903.2020.1738754>
- Osumba, J., Recha, J., Demissie, T., Shilomboleni, H., Radeny, M., & Solomon, D. (2020). State of index-based crop insurance services in east Africa: Findings from a scoping study to establish the state of index-based crop insurance services in Kenya, Tanzania and Uganda. *CGIAR Research Program on Climate Change, Agriculture and Food Security*, 1(1), 1–4. <https://reliefweb.int/report/united-republic-tanzania/state-index-based-crop-insurance-services-east-africa-findings>.
- Peffer, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, 24(3), 45–77. <https://doi.org/10.2753/MIS0742-1222240302>
- Prause, L., Hackfort, S., & Lindgren, M. (2021). Digitalization and the third food regime. *Agriculture and Human Values*, 38(3), 641–655. <https://doi.org/10.1007/s10460-020-10161-2>
- Puri, D. (2016, November 30). *John Deere leads the way with IoT-driven precision farming*. *Network World*. Retrieved from <https://www.networkworld.com/article/3145640/growing-more-with-less-john-deere-leads-the-way-with-iot-driven-precision-farming.html>.
- Qureshi, R., Mehboob, S. H., & Aamir, M. (2021). Sustainable green Fog computing for smart agriculture. *Wireless Personal Communications*, 121(2), 1379–1390. <https://doi.org/10.1007/s11277-021-09059-x>
- Qureshi, S. (2015). Are we making a better world with information and communication technology for development (ICT4D) research? Findings from the field and theory building. *Information Technology for Development*, 21(4), 511–522. <https://doi.org/10.1080/02681102.2015.1080428>
- Rao, T. P. R. (2004). *ICT e-Governance for rural development*. Governance in development: issues, Challenges and Strategies, Gujarat, December 2004. <https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=42ef9d82cd6d842901b3baf34c7900b1b552ee7a>
- Rutsaert, P., Chamberlin, J., Oluoch, K. O., Kitoto, V. O., & Donovan, J. (2021). The geography of agricultural input markets in rural Tanzania. *Food Security*, 13, 1379–1391. <https://doi.org/10.1007/S12571-021-01181-9>
- Saiz-Rubio, V., & Rovira-Más, F. (2020). From smart farming towards agriculture 5.0: A review on crop data management. *Agronomy*, 10(2), 1–21. <https://doi.org/10.3390/agronomy10020207>
- Samoilenko, S., & Osei-Bryson, K. M. (2021). An approach to modelling complex ICT4D investment problems: Towards a solution-oriented framework and data analytics methodology. *European Journal of Information Systems*, 1–21. <https://doi.org/10.1080/0960085X.2021.1992306>
- Sanga, C. A., Tumbo, S. D., & Mlozi, M. R. S. (2014). System design and ICT adoption in agricultural extension services delivery in Tanzania. In K. J. Bwalya (Ed.), *Technology development and platform enhancements for successful global E-government design* (pp. 282–306). IGI global. <https://doi.org/10.4018/978-1-4666-4900-2.ch015>
- Sanga, C. A., Tumbo, S. D., Mussa, M., Mwamkinga, G. H., & Haug, R. (2013). On search for strategies to increase the coverage of agricultural extension service: Web- based farmers' advisory information system. *International Journal of Computing and ICT Research*, 7(1), 42–55. <http://www.ijcir.org/volume7-issue1/article5.pdf>
- Sanka, M. B., & Nkilijiwa, A. L. (2021). Access to agricultural credit for smallholder farmers in shinyanga region – Tanzania. *East African Journal of Social and Applied Sciences*, 3(1), 181–191. <https://journals.mocu.ac.tz/index.php/eaj-sas/article/view/109>
- Schrijver, R. (2016). *Precision agriculture and the future of farming in Europe*. Retrieved from [https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS\\_STU\(2016\)581892\\_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf).

- Schroeder, K., Lampietti, J., & Elabed, G. (2021). *What's cooking: Digital transformation of the agrifood system*. World Bank. <https://openknowledge.worldbank.org/handle/10986/35216>
- Shao, D., & Edward, S. (2014). Combating fake agro-inputs products in Tanzania using mobile phones. *International Journal of Computer Applications*, 97(17), 21–25. <https://doi.org/10.5120/17099-7681>
- Shapa, M., Trojer, L., & Machuve, D. (2021). Mobile-based decision support system for poultry farmers: A case of Tanzania. *International Journal of Advanced Computer Science and Applications*, 12(2), 584–590. <https://doi.org/10.14569/IJACSA.2021.0120273>
- Siemon, D. (2022, February 10). *Methods in Design Science Research*. Wowchemy. Retrieved from <https://design-science-research.de/en/post/methods-in-dsr/>.
- Silver, L., & Johnson, C. (2018). *Internet connectivity seen as having positive impact on life in Sub-Saharan Africa: But digital divide persist*. Retrieved from [www.pewresearch.org](http://www.pewresearch.org).
- Simbakalia, J. L. (2012). The role of financial sector in agriculture development and industrialization. *Economic and Social Research Foundation*, 4(1), 3–6. <http://esrf.or.tz/docs/Financial-Sector.pdf>.
- Sinda, A. A. (2021, April 20). *Tanzania: Overview of data infrastructure in East Africa*. Bowmans. Retrieved from <https://www.bowmanslaw.com/insights/technology-media-and-telecommunications/overview-of-data-infrastructure-in-east-africa-tanzania/>.
- Smidt, H. J., & Jokonya, O. (2021). Factors affecting digital technology adoption by small-scale farmers in agriculture value chains (AVCs) in South Africa. *Information Technology for Development*, 28(3), 558–584. <https://doi.org/10.1080/02681102.2021.1975256>
- Technical Centre for agriculture and rural cooperation (CTA). (2019). *The digitalization of African agriculture report*. CTA.
- Townsend, T., Lampietti, J., Treguer, D., Schroeder, K., Haile, M., Juergenliemk, A., & Hasiner, E. (2019). *Future of food: Harnessing digital technologies to improve food system outcomes* (pp. 44). World Bank. <http://hdl.handle.net/10986/31565>
- UNCTAD. (2021, December 14). *Data protection and privacy legislation worldwide*. United Nations. <https://unctad.org/page/data-protection-and-privacy-legislation-worldwide>.
- United Nations. (2015). THE 17 GOALS | Sustainable Development. Department of Economic and Social Affairs. Retrieved from <https://sdgs.un.org/goals>.
- United Republic of Tanzania. (1997). *Tanzania agriculture and livestock policy*. Ministry of Agriculture and Co-operative.
- United Republic of Tanzania. (2003). National Information and Communications Technologies Policy. In *Policy* (Issue March).
- United States Department of Agriculture. (2002). *eGovernment Program: eGovernment Strategic Plan FY 2002-FY 2006*. USDA.
- USAID. (2013). *Using ICT to Enhance Marketing for Small Agricultural Producers*. USAID Briefing Paper. Retrieved from [https://agrilinks.org/sites/default/files/resource/files/Using\\_ICT\\_to\\_Enhance\\_Marketing\\_for\\_Small\\_Agricultural\\_Producers.pdf](https://agrilinks.org/sites/default/files/resource/files/Using_ICT_to_Enhance_Marketing_for_Small_Agricultural_Producers.pdf).
- USAID. (2021, December 1). *Agriculture and food security*. U.S. Agency for International Development. <https://www.usaid.gov/tanzania/agriculture-and-food-security>.
- van Dijk, M., Morley, T., Rau, M. L., & Saghai, Y. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food*, 2(7), 494–501. <https://doi.org/10.1038/s43016-021-00322-9>
- Wenner, G., Bram, J. T., Marino, M., Obeysekare, E., & Mehta, K. (2018). Organizational models of mobile payment systems in low-resource environments. *Information Technology for Development*, 24(4), 681–705. <https://doi.org/10.1080/02681102.2017.1311830>
- Winandy, M. (2011). A note on the security in the card management system of the German e-health card. In M. Szomszor & P. Kostkova (Eds.), *Lecture notes of the institute for computer sciences, social-informatics and telecommunications engineering*, 69 LNICT (pp. 196–203). Springer. [https://doi.org/10.1007/978-3-642-23635-8\\_25](https://doi.org/10.1007/978-3-642-23635-8_25)
- World Bank. (2012). *Agribusiness indicators: Tanzania*. World Bank. <https://openknowledge.worldbank.org/handle/10986/26561>.
- Zhang, F., Sarkar, A., & Wang, H. (2021). Does internet and information technology help farmers to maximize profit: A cross-sectional study of apple farmers in shandong, China. *Land*, 10, 390. <https://doi.org/10.3390/land10040390>
- Zhang, G., Wu, X., & Wang, K. (2022). Research on the Impact and Mechanism of Internet Use on the Poverty Vulnerability of Farmers in China. *Sustainability*, 14, 1–16. doi:10.1108/SAMPJ-07-2021-0268
- Zheng, Y., Hatakka, M., Sahay, S., & Andersson, A. (2018). Conceptualizing development in information and communication technology for development (ICT4D). *Information Technology for Development*, 24(1), 1–14. <https://doi.org/10.1080/02681102.2017.1396020>