AMSTERDAM SUSTAINABILITY INSTITUTE INTEGRATIVE PROJECT

Sustainability and Ethics by Design: In the development of digital platforms in low-resource environments

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ABSTRACT

Context. ICT projects in low-resource environments often fail. Furthermore, ICT projects that are introduced by means of development aid often cease to exist once the funding stops. This situation is not sustainable. Moreover, technology can have negative consequences for society, especially in low-resource environments.
Goal. We aim to understand the sustainability and ethical concerns of designing context-sensitive ICT systems in low-resource environments. Our main research question is “Can we define a general good practice for designing sustainable and ethical (software-intensive) systems in low-resource environments?".
Method. To answer the research question, we conducted a case study regarding the redesign of an information system that supports the seed value chain processes in Mali. Based on interviews and focus groups, we modeled and analyzed the sustainability and ethical concerns and proposed context-sensitive changes to the information system that fit the local needs.
Results. The main contribution of this work is a description of a methodology in developing sustainable and ethical software in low-resource environments.
Conclusion. Sustainability can only be measured over time. Hence, to introduce a sustainable system, its context and long-term effects need to be understood. Co-creation can be a tool to facilitate culturally-sensitive ethical consideration in software projects for low-resource environments, however, more general ethical reflection is needed to fully embed ethics in such projects.

KEYWORDS:
Sustainability, Ethics, Food Security, Software Design, Software Engineering, Decision Maps, Mali, Seed Value Chain

1 INTRODUCTION

Despite the rapid technological advances of the past few decades, vast regions of the world remain unconnected and underserved by the information society. Since various studies showed the added value of digital technology in solving local problems [1], efforts are still undertaken to develop ICT services for people in low-resource environments. Moreover, many studies show that software projects in low-resource environments often fail [1]. Whereas the reason for failure can vary from case to case, one pattern emerges, related to a frequent mismatch between the technology and the local context.

1.1 Sustainability

ICT systems in low-resource environments that are part of development aid programs tend to stop performing once the aid finishes [2]. This execution is not sustainable as sustainability requires the functioning of a system to be preserved over an extended period of time [3]. Hence, for ICT systems to be sustainable, the systems need to endure without outside interference.

1.2 Ethics

A second point of concern is the disruptive nature of technology. Rapid technological advances, for example in Artificial Intelligence (AI), are raising widespread concern regarding the possible negative consequences for society. In low-resource environments, this is a greater concern as these environments are more vulnerable, often due to a lack of legal frameworks. Despite some first efforts (*e.g.,* Principles for Digital development[1] and Minimum Ethical Standards in ICT4D research [4]) ethics by design is not yet common practice in digital development for low-resource environments. Ethical reflection in ICT4D is often limited to reflection on the role as researcher (e.g. [5]) and does not encompass the entirety of the project and the consequences of new technology that is being developed, on a lager scale. In order to contribute to sustainable development, ethics need to be taken into account in every facet of an ICT4D project.

1.3 Mali Case Study

To understand the sustainability and ethical concerns of designing context-sensitive ICT systems, we conduct interdisciplinary research between computer science and philosophy in collaboration with the Amsterdam Sustainability Institute (ASI) around the theme Food Security. This research focuses on a case study around the seed value chain in Mali. In Mali, food security is a source of concern as 75% of the population relies on agriculture [6]. The seed value chain concerns the trade of seeds used to grow grains meant for food production. Unfortunately, the seed value chain faces many obstacles such as a lack of communication channels between the involved parties. This causes a mismatch between the supply and demand of the seeds [7]. To improve the trade processes, a seed information system (in this paper referred to as SIS) was introduced by SOS Faim[2] to connect suppliers and customers by allowing them to fill in and retrieve seed stock data. Unfortunately, this platform excludes important stakeholders such as the farmers [7].

1.4 Objectives

Our research focuses on understanding the software design of the SIS and revising it by including sustainability and ethics in the design process. The objectives of our study can be defined into three categories: (1) ICT4D Research community: We aim to describe a method to design and develop a software project in a low-resource environment, and identify lesson-learned and dimensions to consider. This includes the technical, economic, social, and environmental sustainability dimensions together with an analysis of the ethical aspects. (2) Software Engineering: We aim to influence the design decisions of the developers of the SIS to ensure that sustainability and ethical considerations are included in the design phase. (3) Stakeholder Community: We aim to support the stakeholders of the Malian seed value chain with models and documentation to ease communication and provide insights into the development process.

1.5 Research Question

Our main research question is *"Can we define a general good practice for designing sustainable and ethical (software-intensive) systems in low-resource environments?".*

1.6 Methodology

We conducted several interviews with local stakeholders to understand the process of designing software in an environment that requires a completely new approach due to the lack of digital infrastructure and internet access. Furthermore, we identified the

[1] digitalprinciples.org/principles
[2] www.sosfaim.be

Sustainability Quality (SQ) concerns of the SIS by using a Decision Map (DM) [8]. Thereafter, we propose changes to the SIS so that it is context-sensitive. Afterward, we conducted several semi-structured interviews with people from various cultural backgrounds who are experts in the fields of ethics, technology, and ICT4D to gather recommendations to embed ethics into ICT4D projects. After which we apply these findings to the Mali seed project.

1.7 Contributions

We generalize our findings by formulating lessons-learned in designing context-sensitive (ICT) systems in low-resource environments. On top of this, we have shown how co-creation can be a tool to facilitate ethical reflection during an ICT4D project. The main contribution of this work is a description of a methodology in developing sustainable and ethical software in low-resource environments.

1.8 Paper Structure

This paper is structured as follows: first, we discuss related work (Section 2), background information (Section 3), and the project objectives and study design (Section 4). Thereafter, we present the first research phase in which the current SIS is described and analyzed (Section 5). Afterward, in the second research phase, we propose a new SIS that addresses the limitations of the current SIS (Section 6). Then, the ethical dimensions of introducing software in unfamiliar environments are discussed (Section 7). Lastly, we discuss the results (Section 8) and conclude the work (Section 9).

2 RELATED WORK

This interdisciplinary research project relates to and builds on the work of various research communities, in various knowledge domains. Therefore, multiple approaches are combined. As real-world research related to the Sustainable Development Goals (notably SDG2: "zero hunger") it links to work in the domain of food security [9, 10]. The present research builds on research previously carried out in low-resource environments in West Africa, by *e.g.,* Gyan [11], Baart *et al.*[12], and De Boer *et al.* [13, 14].

The present research can be considered ICT4D (Information and communication technologies for development) research, from an action design research perspective [15]. The majority of ICT4D studies are empirical or desktop social sciences studies, often from the MIS (Management Information System) perspective [16, 1, 17]. In contrast, our study builds on ICT4D design research combined with a software engineering approach by e.g. Lago *et al.*[8, 3], Rolland [18], and Maclean [19].

Methodologically, in this research project, we take a reflective design and action research, which includes practice: agile development methods, similar to what is described by Dingsoyr [20] and Leffingwell [21], reflection *e.g.,* [22], and ethics [23, 24, 25]. It also draws from requirements engineering, sustainable software architecture [26, 27, 28] and conceptual modeling [18, 29], yet adapted to the complexity of low-resource environments.

3 BACKGROUND

Our study extends the research of Bon et al. [7, 30] regarding the seed value chain in Mali. In Section 3.1, we explain the context of the seed value chain processes based on the information published in [7, 30]. Furthermore, our study uses DMs introduced by Lago [8] to understand the SQ concerns of the SIS. A general explanation of DMs together with definitions of its concepts is presented in Section 3.2. Lastly, background information regarding ethics in software-development is provided in Section 3.3.

3.1 Seed Value Chain in Mali

Mali is a West-African Country with a population of 20 million people. Feeding the population is a major challenge, given the arid (and changing) climate, erratic rainfall, and widespread rain-fed subsistence agriculture. Hence, there is a need for intensification of agriculture to feed the (fast-growing) population. The Malian government adopted an agricultural development strategy to reduce poverty while maintaining the diversity of food production [6].

A part of this strategy is using enhanced seeds for food production. These basic input seeds are called *semences de base*. Semences de base can be used to grow several grains (such as Sorghum, Corn, Rice, Cowpeas, Sesame, and Fonio) meant for food production. The Institute of Rural Economics (IER) produces the semences de base and farmers use the semences de base to produce R1 seeds. Accordingly, from R1 seeds, farmers can harvest R2 seeds. Finally, from R2 seeds farmers can produce regular seeds. R1 and R2 seeds are of higher quality compared to regular seeds and can thus be sold for a higher price. Nevertheless, to be able to sell R1 and R2 seeds, the seeds need to be certified by LaboSem (a governmental institution under the Malian Ministry of Agriculture). This is a slow process that can take up to 3 months.

Farmers who produce R1, R2, and regular seeds usually sell them to farmer cooperatives at a fixed price. There are many different forms and layers of farmer cooperatives. The cooperatives store and certify the R1 and R2 seeds. Furthermore, the cooperatives sell the seeds (at a negotiable price) to other farmers who use the seeds to grow the grains. The Association des Organisations Professionnelles Paysanned (AOPP) is an umbrella organization that regulates the seed value chain and aims to unite the farmer cooperatives. A means to accomplish this is the SIS that intends to connect the buyers of seeds and the suppliers. The SIS is a central part of our research and is described in details in Section 5.2.

Many issues arise in the seed value chain. We following summarizes the most commonly mentioned ones elicited from interviews and focus groups with local stakeholders from [7, 30]:

I-1 Lack of buyers. Often, farmers cannot find buyers and hence cannot sell their whole stock of seeds. This can be due to an occasional good rainy season and thus a good harvest. More frequently, this is due to a lack of communication channels to find appropriate buyers. Especially farmers in rain-fed agriculture are most vulnerable to price and demand fluctuations.

I-2 Many stakeholders. There are many involved parties and organizational layers in the seed value chain processes. This causes slow, bureaucratic processes and, overall disorganization.

I-3 Lack of information. There is a lack of information in many stages of the seed value chain. For instance, cooperatives do not know the status of the seed certification process. Furthermore, there is great uncertainty regarding the seed trade. Cooperatives often do not know what seed quantity is sold, currently available, or expected. Moreover, there is little knowledge concerning future demand. This can lead to a lack of seed stock in one region and an excess of seed stock in another region.

I-4 Lack of communication. A common problem is the fact that the seeds are not distributed equally over the regions. It is no exception that one region has a shortage of seeds whereas in other regions farmers cannot sell their full stock of seeds. Currently, there are no effective communication channels that allow this demand and supply to match.

I-5 Non-transparent processes. The processes in the seed value chain are often non-transparent to the farmers and local farmer cooperatives. For instance, there is a lack of information on the certification process.

I-6 Slow certification process. R1 and R2 seeds are of higher quality compared to regular seeds and hence can be sold for a higher price. In order to sell R1 and R2 seeds, the farmer or cooperative has to send a small sample of the seeds to LaboSem. This certification process can take up to 3 months due to a lack of capacity and information. This lengthy certification process is a frequently mentioned problem by farmers [30].

I-7 Lack of organization. There is a lack of planning and organization at all levels. Due to the long certification process, farmers need to be able to plan the seed production ahead. However, farmers cannot estimate future demand due to non-transparent processes and a lack of information.

I-8 Lack of finance. The lack of finance manifests in a lack of financial management skills at the farmer level which, in turn, leads to poor planning of the seed production. In order to produce the seeds, farmers have to invest in fertilizers and pesticides. However, the farmers often do not know whether they will make profit due to uncertainties such as crop loss, price fluctuations, a mismatch between buyers and sellers. Sometimes farmers receive micro-finance loans. However, this leads to more pressure on farmers as revenue is not guaranteed.

I-9 Lack of trust. The relationship between buyers and sellers/producers lacks trust. Moreover, farmers experience dishonesty and corruption by other stakeholders in the seed exchange network.

I-10 Lack of semences de base. Often, farmers experience accessing semences de base (basic input seeds) as difficult. Some farmers do receive semence de base without payment from development projects (e.g. ICRISAT [31]).

Solving some of these issues can be facilitated by ICT, however, many ICT related issues arise in the project context. For instance, farmers, buyers, and cooperatives often lack or have an unstable internet connection, do not have access to smart devices such as a laptop or smartphone, or can be are illiterate.

The seed value chain project aims to understand the context of the seed value chain in Mali and to support the improvement of information and communication with the co-creation of innovative ICT solutions. As part of the seed value chain project, several interviews and focus groups have been hosted with local stakeholders to understand the complications that arise in the seed value chain. An overview of these interviews and focus groups is presented in [7, 30].

The seed value chain project follows the ICT4D methodology which describes a strategy to develop information systems in low-resource environments [32]. This methodology entails that information systems should (1) serve local needs, (2) fit the local complexity of the context, and (3) are not unethical or harmful for local stakeholders.

The seed value chain project has as objective to ease the trade processes of seeds meant for food production. To accomplish this, a prototype of a context-sensitive information system will be designed, developed, and tested. This research paper contributes to this study by analyzing the stakeholder needs, the local ecosystem, and sustainability and ethical concerns. Moreover, goals and requirements of a context-sensitive SIS are proposed. The technical requirements for an information system in a low-resource environment (e.g. no internet connection) are defined in the work of the Web alliance for Regreening in Africa (W4RA) project [33].

3.2 Decision Maps

In this study, we aim to frame the SQ concerns relevant for designing context-sensitive, self-sustaining ICT solutions. In order to explore the current SIS and propose an improved SIS, we use DMs introduced by Lago [8] to frame the SQ concerns. DMs present SQ concerns of a software-solution in one picture and allow reasoning about its (potential) effects.

Lago uses the following definitions to define sustainability in software engineering: *"the capacity to endure"* and *"to preserve the function of a system over an extended period of time"* [8]. In particular, it is important to note that sustainability should not be confused with impact. Impact is measured at a certain point in time whereas sustainability can only be observed over a significant period of time [8]. Technology aims to support sustainability. However, this is not always included in the design of the system. To ensure that the functions of a system are preserved over an extended period of time, its design should consider the SQ concerns. DMs can facilitate in framing SQ concerns of a selected problem and their expected or experienced inter-dependencies.

The advantage of modeling a software solution using DMs is the clarification of the trade-offs between sustainability dimensions and the evolution over time. DMs frame SQ concerns and digital features/requirements in four sustainability dimensions. Namely, (1) **technical sustainability** which addresses the "*long-term use of software-intensive systems and their appropriate evolution in an execution environment that continuously changes*", (2) **economic sustainability** that focuses on "*preserving capital and (economic) value*", (3) **social sustainability** considers "*supporting current and future generations to have the same or greater access to social resources by pursuing generational equity. For software-intensive systems, this dimension encompasses the direct support of social communities in any domain, as well as the support of activities or processes that indirectly create benefits for social communities*", and (4) **environmental sustainability** aims at "*improving human welfare while protecting natural resources. For software-intensive systems, this dimension aims at addressing ecologic concerns, including energy efficiency and ecologic awareness creation*" [8]. Furthermore, the impact of an effect of the software solution can be immediate, enabling, or systemic. Immediate impacts refer to: "*changes which are immediately observable*", enabling impacts arise from: "*use over time*", and systemic impacts refer to "*persistent changes observable at the macro level*" [8]. Macro structures are required to change in order to create a sustainable environment.

3.3 Ethics in ICT

While ICT has become an integral part of human life, and technology has proven to enhance daily living, it can not be regarded as bringing solely solutions and development. Some authors have argued that technology has the potential to inflict harm and contribute to greater inequality [**piketty2014capital**, 34]. In China, for example, high-tech surveillance technology has enabled the government to suppress minorities [35]. Furthermore, far-ranging negative consequences can be ascribed to AI. AI has exhibited discrimination, for example, by not accurately recognizing black people [36], polarized political debate by spreading misinformation via social media [37], and contributed to injustice when used in court settings [38].

Recognizing these unintended and possibly detrimental consequences of technology after they have occurred, is insufficient. Grosz et al. [25] advocate to embed ethics in the design process of technology, to prevent these harmful consequences. Developers should envision potential consequences of their technology and build measures to prevent them. To do so, different values have to be weighed to constitute what is right to do. Grosz et al. [25] argue that this reflection should take place throughout the design process, to avoid negative consequences and discontinue potentially unethical projects before they inflict any harm. Grosz aims to embed ethics in the development process by educating computer science students in ethical thinking and learning them about a variety of ethical theories, such as *deontology* [39], *care ethics* [40], and *consequentialism* [41]. This should equip technology developers to oversee possible negative consequences of their design and weigh competing interests and principles when developing software.

3.3.1 Ethics in ICT4D

As of know, ethics has not adequately reached ICT4D practises, while technology has to potential to be even more harmful in these low-resource environments. For example, for mobile data in Africa, Linnet Taylor [42] has shown that technology users in low-resource environments are particularly vulnerable to harmful effects of technology.

How Grosz et al. envisions embedding ethics in ICT4D projects is vague for they do not advocate for a single fixed approach to incorporate ethics in the design phase. Rather, in her talk for DigHum on TUWien she stresses the uniqueness of each case which accordingly calls for a unique approach. While such a view honors the complexity of ethical issues, it fails to offer concrete tools to embed ethics. Furthermore, no attention is given to the possible subjectivity of ethical decision making. In many ICT4D projects, such as the Mali seed case, cultural differences between developers and the envisioned user community are often present in the development process.

3.3.2 Need for Cultural Sensitivity in Ethics

Multiple studies suggest that cultures foster differences in their ethical judgment [24]. This suggests the need for cultural sensitivity when embedding ethics in the design process of ICT4D projects. Multiple studies have shown that ICT4D projects often lack cultural sensitivity due to a variety of reasons. Dearden et al. [5], for example, stress the need to avoid so-called *Bungee-jumping research* in ICT4D, where privileged researchers make short visits to rural areas to gather data but make no effort to understand the local context. The authors argue that such research is unethical as it is ineffective and can impose harm by collecting unreliable data. Bai et al. [43] question the dominant role of the Global North in developmental work in the Global South. This dominance can contribute to a lack of acknowledgment for the local context which threatens to diminish the possible beneficial effects of developmental work.

3.3.3 Addressing Ethics in ICT4D

These examples demonstrate the need for ethical consideration, throughout the design process, with a focus on cultural sensitivity in ICT4D projects. The ICT4D community has responded by developing Minimum Ethical Standards in ICT4D research [4]. These standards urge researchers to reflect on certain issues, such as cultural differences, and to use appropriate research methods. Furthermore, it mentions basic principles which should be upheld, such as to refrain from doing harm and discrimination.

Although the standard [4] is a valuable starting point to discuss what ethical ICT4D entails, it fails to offer concrete tools for developers to incorporate ethical consideration into the design of their projects. Therefore, embedding ethics is not yet common practice in these projects. Concrete solutions to make room for ethics and cultural sensitivity in ICT4D projects are needed to make standards such as the Minimum Ethical Standards in ICT4D research more tangible and less abstract and idealistic.

4 PROJECT DESCRIPTION

This study is initiated by the Amsterdam Sustainability Institute (ASI) around the theme ICT for Food Security (ICT4FoodSec). This concerns food and nutrition security in low-resource environments. The objectives of our study are presented in Section 4.1. Thereafter, we describe the study design in Section 4.2.

4.1 Objectives

This study aims to describe a method to design and develop context-sensitive ICT solutions in low-resource environments. The seed value chain in Mali is used as a case study to describe this process. In the seed value chain in Mali, there is a lack of ICT resources, infrastructure, and experience. Hence, the software engineering process needs to be adapted to this situation. This study is relevant to the ICT4D research community, software engineers, and stakeholders of the Malian seed value chain. Hence, the study objectives are divided into three sub-categories:

ICT4D Research community. We aim to describe a method to design and develop a software project in a low-resource environment, and identify lesson-learned and dimensions to consider. This includes the technical, economic, social, and environmental sustainability dimensions. Furthermore, we aim to include ethical aspects into the design process.

Software Engineering. We aim to influence the design decisions of the developers of the SIS to ensure that ethical and sustainability considerations are included in the design phase.

Stakeholder Community. We aim to support the stakeholders of the Malian seed value chain with models and documentation to ease communication and provide insights into the development process.

To accomplish these objectives, we analyze the current context of the seed value chain in Mali, and, in particular, the role that the SIS plays therein. From this analysis, we frame sustainability concerns in DMs and present general lessons learned in designing sustainable, context-sensitive information systems. Moreover, we analyze the requirements to embed ethics into the design process.

4.2 Study Design

The overarching research question is: "*Can we define a general good practice for designing ethical and sustainable (software-intensive) systems in low resource environments?*". In this research, we focus on the sustainability goal to design (information) systems that can be maintained over time without outside intervention and take ethical considerations into account. This study consists of three research phases. Each phase is described below and visualized in Figure 1.

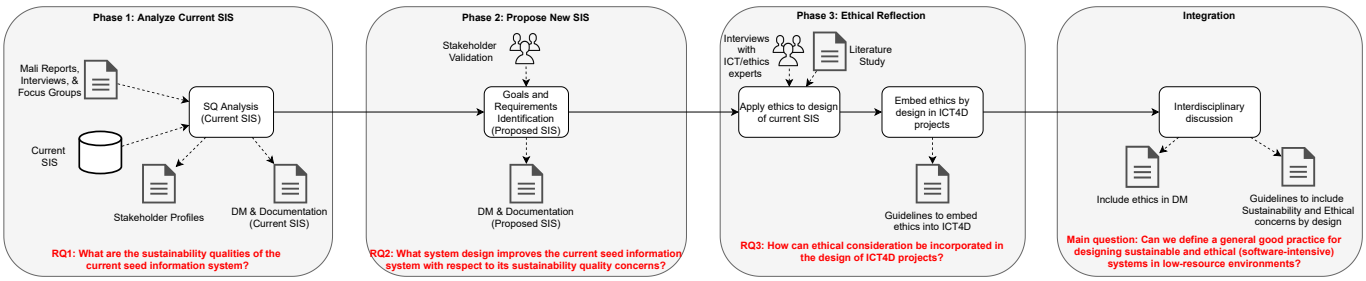

Figure 1 Overview of the study design.

Phase 1: Analyze Current SIS. We aim to understand the SQs of the current SIS. Accordingly, the following research question is addressed: "*What are the sustainability qualities of the current seed information system?*". To answer this research question, we need to understand the context around the seed value chain in Mali and the role of the current SIS therein. The input of this research phase consists of the interviews and focus groups as documented in [7, 30]. Moreover, the current SIS itself functions as input. The SQs of the current SIS are analyzed using DMs. To properly identify the SQ concerns, the stakeholders of the system need to be involved. We constructed stakeholder profiles based on the stakeholder interviews and focus groups. The output of Phase 1 consists of the documentation of the current SIS which includes a description, UML use-case diagram, and DM.

Phase 2: Propose New SIS. We aim to propose a system design that addresses the SQ concerns identified in Phase 1. The related research question is: "*What system design improves the current seed information system with respect to its sustainability quality concerns?*". To answer this research question, we identified goals, functional, and quality requirements.

This is shared with the developers of the SIS who extent the current SIS with a voice-interface. The ICT4D methodology [32] was adapted to support the process of defining the requirements and design space. Furthermore, a DM was constructed to assess the sustainability implications of the proposed, context-sensitive SIS.

Phase 3: Ethical Reflection. We aim to propose a method to embed ethics into the design of an ICT4D project such as the Mali seed project. On the premise that ethical judgments do not have universal reach, we aim to gather insight into ways to address cultural sensitivity when considering ethics in the design process of an information system. The related research question is "*How can ethical consideration be embedded during the design process of an ICT4D project?*". To answer this question, we conducted semi-structured interviews with people with various cultural backgrounds, who are experts in the fields of ethics, technology, and ICT4D. These interviews question their views on embedding ethics into ICT4D work. We analyzed the recommendations and applied them to the Mali seed case. Furthermore, we reflected on these recommendations and offered solutions to incorporate these into the design of an ICT4D project.

After these research phases, we integrated the lessons-learned by means of an interdisciplinary discussion (see the last phase **Integration** in Figure 1). This allowed us to integrate the ethical concerns into the DM. Moreover, we created a list of guidelines meant to integrate sustainability and ethical concerns into the design of software-intensive systems in low-resource environments.

5 PHASE 1: ANALYZE THE CURRENT SEED INFORMATION SYSTEM

This section presents an analysis of the current SIS and is the output of Phase 1 (see Section 4.2). First, Section 5.1 provides an overview of the stakeholders of the SIS. Next, Section 5.2 describes the current SIS. Last, Section 5.3 presents the DM that frames the Sustainability Quality (SQ) concerns of the SIS.

5.1 Stakeholder Profiles

Based on a series of interviews carried out on-site and reported in [7, 30], we extracted the information needed to define the stakeholder profiles for our study. The definitions of the terms used in the stakeholder profiles are listed in Table 1 and the results are presented in Tables 2-10.

Table 1 Definitions of Terms to Describe Stakeholder Profiles

ID	A short identifier referring to the relevant stakeholder.
Description	A brief description of the role of the relevant stakeholder in the Malian seed value chain.
Goals	Main goal(s) of the stakeholder in order to run and maintain their organization/business.
Means	Means the stakeholder has access to/uses in order to accomplish their goal(s).
Barriers	External events or phenomena hindering the goal(s) of the stakeholder.
Concerns	Interest in a system relevant to one or more of its stakeholders [44]. In this case, this refers to the interests of the relevant stakeholder in the SIS.

Table 2 Stakeholder Profile of The Association des Organisations Professionnelles Paysanned (AOPP)

ID	ST-01-AOPP
Description	The Association des Organisations Professionnelles Paysanned (AOPP) is an overarching association of professional farmer cooperatives. The AOPP is the owner of the current SIS.
Goals	• Inform farmer cooperatives • Facilitate and support farmers • Improve the seed value chain
Means	• Funding from farmer cooperatives • Owner of the current SIS
Barriers	• Poor communication channels with farmers and farmer cooperatives
Concerns	• Need for (up-to-date) information about seed offerings from farmers and farmer cooperatives • Need for (up-to-date) information about (future) demand of seed customers • Need for ICT systems that facilitate the seed value chain and can operate without internet connection (as the many involved stakeholders have no internet connection/smart devices) • Need for efficient communication channels with illiterate stakeholders

Table 3 Stakeholder Profile of Farmer Cooperatives

ID	ST-02-FarmerCooperatives
Description	The farmer cooperatives unite farmers. There are many layers of cooperatives. The cooperatives form cartels and decide the selling price of seeds. Farmers sell their seeds to the cooperatives, and the cooperatives store, certify, and sell the seeds.
Goals	• Support farmers in selling their seeds • Make profit on the resale of seeds
Means	• Communication channel between cooperatives • Communication with farmers • Communication with the AOPP • Insert and update stock data in the SIS • Physically store seeds • Transfer certification requests
Barriers	• Long seed certification process period • Lack of connectivity and experience with smart devices to insert and update stock data
Concerns	• Need for information with respect to: – Farmer seed stock – Farmer's seed production plan – Seed demand – Certification status

Table 4 Stakeholder Profile of Farmers

ID	ST-03-Farmers
Description	Farmers produce seeds (such as Sorghum, Corn, Rice, Cowpeas, Sesame, and Fonio) for food production.
Goals	• Produce seeds • Make profit
Means	• Cooperation with the farmer cooperatives • Informal selling channels
Barriers	• Lack of funds to invest • Fluctuating prices • Long duration certification process • Lack of internet connection, digital skills, and smart devices • Illiteracy • Language barrier as most farmers speak local languages (such as Bambara) and information is often provided in French
Concerns	• Need for information with respect to: – Retrieval basic input seeds – Quantity to produce for next season – Variety of seeds to produce – Seed prices – Status certification – Demand for seeds of farmer cooperatives and customers

Table 5 Stakeholder Profile of Wholesale Customers

ID	ST-04-WholesaleCustomers
Description	Wholesale Customers negotiate at all levels (AOPP, Farmer Cooperative, and Farmer). They often buy large amounts of seeds that they order in advance.
Goals	• Buy a large quantity of high quality seeds at a fair price in advance
Means	• Internet access
Barriers	• Uncertainty whether the requested quantity and quality can be delivered • Uncertainty whether the requested quantity and quality is available • Little communication channels with the seller (farmers and farmer cooperatives)
Concerns	• Need for information regarding availability of requested quantity and quality • Need for communication channel with farmers and farmer cooperatives

Table 6 Stakeholder Profile of Local Customers

ID	ST-05-LocalCustomers
Description	Local customers are farmers who produce grains meant for food production. To produce these grains, they need seeds. The local customers negotiate with farmer cooperatives and farmers. They often buy small amounts of seeds that they need immediately.
Goals	• Produce cereal
Means	• Informal network with farmers
Barriers	• Fluctuating prices • No internet access
Concerns	• Need for information on availability, price, and location of seeds

Table 7 Stakeholder Profile of Radio Stations

ID	ST-06-Radio
Description	There are local and regional radio stations. The radio stations reach many people, including farmers, cooperate- and local customers.
Goals	• Inform • Make profit
Means	• Commercials
Barriers	• Poor access to (seed) information
Concerns	• Need for accessible seed information

Table 8 Stakeholder Profile of The National Agriculture Division (DNA)

ID	ST-07-DNA
Description	The National Agriculture Division (DNA) is part of the Malian government and operates under the Malian Ministry of Agriculture [6].
Goals	• Serve society • Improve food security • Facilitate trade
Means	• Agricultural policy implementation • Objectives and production standards formulation • Maintenance of the official catalogue of seed varieties
Barriers	• Political instability • Economic situation • Climate change
Concerns	• Need for information from grass roots

Table 9 Stakeholder Profile of The Institute of Rural Economics (IER)

ID	ST-08-IER
Description	The Institute of Rural Economics (IER) is responsible for introducing, creating, and improving varieties of seeds (semences de base). The IER has to make the seeds available to farmers. Hence, it has to respond to the demand in order to deliver in time. The IER provides the National Seed Service (SSN) with R1 seeds. The SSN is part of the Ministry of Agriculture and coordinates the national seed plan [6].
Goals	• Introduce, create and, improve seeds varieties
Means	• Laboratory work
Barriers	• Lack of efficient communication channels with farmers and farmer cooperatives to estimate the demand.
Concerns	• Need for efficient communication channels with farmers and farmer cooperatives.

Table 10 Stakeholder Profile of Seed Laboratory LaboSem

ID	ST-09-LaboSem
Description	Governmental institution under the Ministry of Agriculture that is responsible to carry out field controls of the (R1, R2) seeds (re)produced by farmers. Farmers have to send a small sample of their seed production to the laboratory and LaboSem certifies (or rejects) the seeds produced by the farmers [6].
Goals	• Provide service to farmers • Ensure seed quality
Means	• Field control • Seed analysis • Laboratory work • Provide certificates
Barriers	• Work overload • Lack of technical means • Lack of communication channels
Concerns	• Need for efficient communication channels with farmers and farmer cooperatives.

5.2 Documentation of the Current Seed Information System

The current SIS aims to support the seed value chain and is hosted by the AOPP. This project started in 2018 and is financed by SOS Faim[3] (a Belgian NGO/donor organization) [7]. Currently, the SIS consists of a web-interface[4] and an Android application[5] that both connect to a database that stores the seed data. The main functionality of the SIS is to connect customers to farmer cooperatives (who sell and store the seeds). The goal of exchanging the seed information is to bridge the imbalance of supply and demand. The SIS allows farmer cooperatives to fill in their available variety and quantity of seeds and customers to query their requested variety and quantity of seeds. If the requested quantity is in stock, the contact details of the relevant cooperative(s) are displayed. The members representing each farmer cooperative, received a smart device from SOS Faim to access the application.

Figure 2 Screenshot of the landing page of the SIS.

Figure 3 Screenshot of the SIS page that allows customers to query their seed request.

The customer interface is available through the following link: aopp-mali.com/stock-search.php. Two screenshots of the SIS are presented in Figure 2 and 3. Figure 2 shows the landing page and Figure 3 presents the page in which customers can query their seed request. The customer searches for the required seed variety and types in the quantity. After clicking `RECHERCHER` (French for 'search'), a list appears with contact details of farmer cooperatives that have the requested variety and quantity in stock.

The current SIS does not succeed in achieving its objectives (e.g. to connect the customers and suppliers). This is mainly due to a lack of users and, therefore, a lack of data. The farmer cooperatives are required to manually fill in the seed stock data. To do

[3] www.sosfaim.be
[4] aopp-mali.com/
[5] play.google.com/store/apps/details?id=com.mcorpmali.aopp_collect

so, the representatives of farmer cooperatives received a smart device from SOS Faim. However, the farmer cooperatives often lack the digital skills and/or motivation to fill in the seed stock data. Furthermore, farmers do not have access to the current SIS as they usually are not in the possession of a smart device, internet connection, are illiterate, and experience a language barrier [7]. This further amplifies the lack of data. As a consequence, when customers use the SIS, it is likely that their seed request is not available. Even though the seed request might actually be in stock, however, the data has not been entered. Hence, the customers are likely to lose their trust in the system. As an effect, farmer cooperatives further lose incentives to fill in the seed stock data.

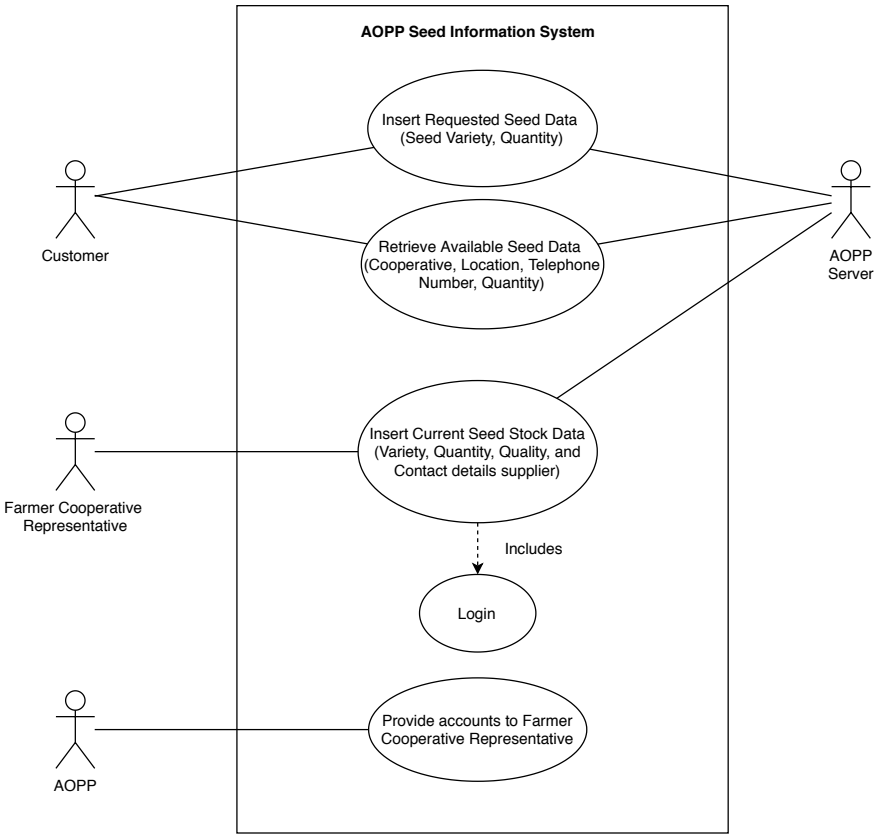

Figure 4 UML Use Case Diagram of the AOPP Seed Information System.

We created a UML Use Case Diagram of the SIS and verified this with Mohamed Malet (developer of the SIS). The Use Case Diagram is presented in Figure 4. The users of the system are the *Customer* and the *Farmer Cooperative Representative*. The *Customer* does not need to login to the system. When accessing the web-interface of the SIS, the *Customer* can immediately insert their request that contains the seed variety and desired quantity. The *AOPP Server* looks up whether the requested seeds are available and returns the list of farmer cooperatives in which the requested amount of seeds is in stock, together with their contact details. For this functionality to work, the *Farmer Cooperative Representative* is responsible for inserting and updating their seed stock information. This action does require the *Farmer Cooperative Representative* to log in using verified credentials which are provided by the *AOPP*.

5.3 Decision Map of the Current Seed Information System

The sustainability goal of this study is to enable a system that is operated and maintained without external intervention *over time*. We constructed a DM of the current SIS (see Figure 5) and listed the definitions of the features and concerns (see Appendix A). The information is based on the study by Bon et al. [7, 30].

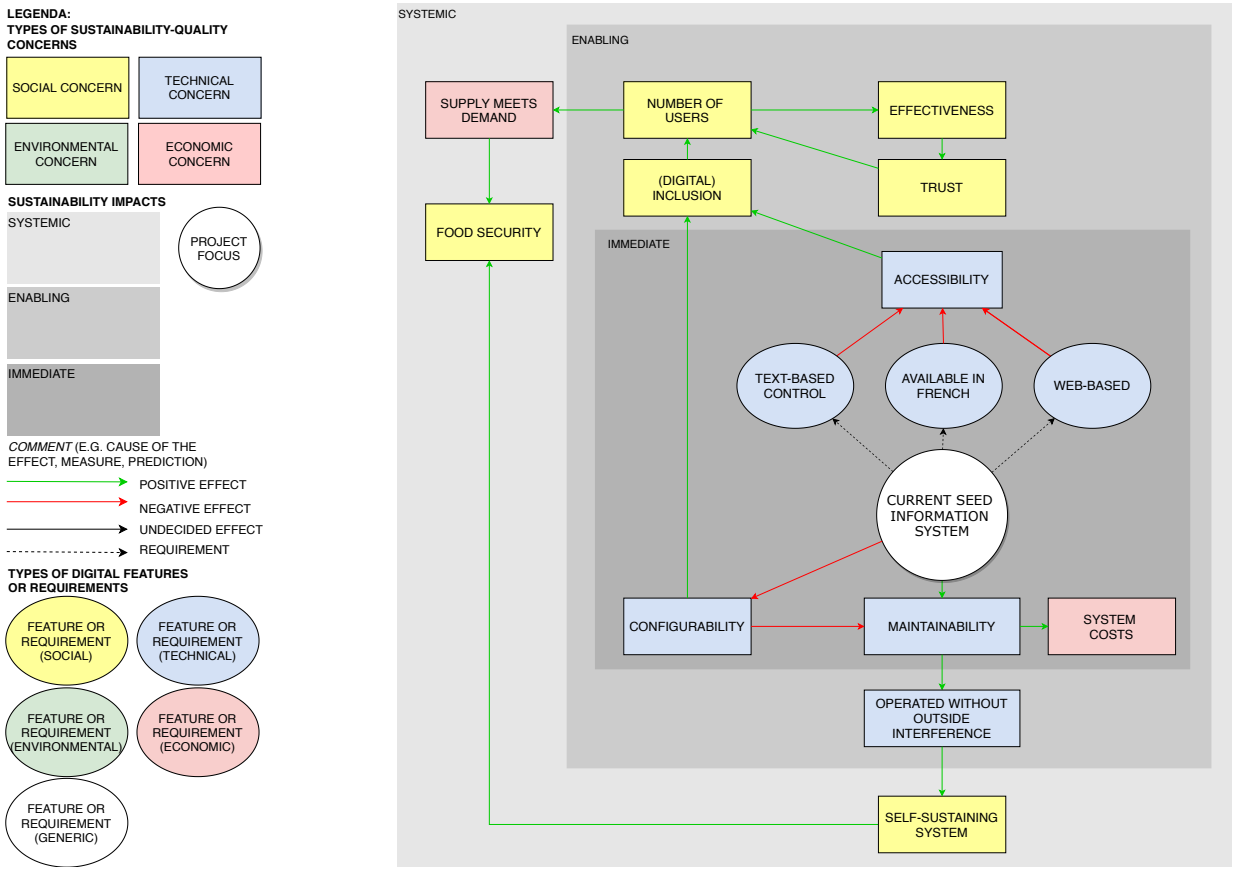

Figure 5 DM that presents the features, sustainability concerns and inter-dependencies of the current SIS of the AOPP.

The current SIS is *text-based*, *available in French*, and *web-based*. These system features affect the Sustainability Quality (SQ) concerns. For instance, the seed stock information being *text-based* harms *accessibility* as not all stakeholders are literate. Furthermore, the SIS being merely *available in French* decreases the *accessibility* as not every stakeholder understands French. Often, stakeholders speak local languages such as Bambara. Lastly, the SIS being *web-based* has a negative effect on *accessibility* as many stakeholders do not have access to an internet connection and/or smart device.

Accessibility has a positive effect on *(digital) inclusion*; if more users have access to the SIS, more stakeholders are included. Consequently, the *number of users* of the SIS would increase. This activates a network effect [45]: when the *number of users* increases, the *effectiveness* increases (as the SIS needs stock data for customers to be able to look up their request), and accordingly, the *trust* of (future) users increases. Again, this would have a positive effect on the *number of users*. Looking from a macro perspective, as more users share their seed stock data and requests using the SIS, we expect a positive effect on the *supply meets demand*. This is an important step towards *food security*. However, a problem of the current SIS is that this network effect is not activated due to the poor *accessibility* of the system. Accordingly, the *supply* of seeds will not actually *meet the demand* as the system requires active users. The *number of users* does not increase due to inadequate *accessibility* measures. Therefore, we state that the current SIS is not context-sensitive, i.e., it is not adequately adapted to society.

Looking at the bottom half of the DM, we modeled a positive effect between the current SIS and *maintainability*. This is caused by the system having relatively few features and not being configurable. There exists a negative effect from *configurability* to *maintainability*: as the number of system versions increases, the system becomes more complex and, hence, difficult to maintain. Furthermore, as maintainability has a positive effect on the *system costs*, the system costs of the current SIS are expected to be relatively low due to its lack of configurability. The lack of *configurability* impacts the previously explained network-effect negatively as having little system extensions refrains stakeholders from accessing the SIS. Nevertheless, an advantage of the current SIS is that its positive effect on *maintainability* ensures sufficient resources to keep the system operational. As a consequence, the probability of the system being *operated without outside interference* (e.g. the dependence on financial subsidies from development aid organizations) increases. The system being able to *operate without outside interference* increases

the chance of the system being *self-sustaining*. This means that the local community is capable of operating and maintaining the system with local resources. Once the system is *self-sustaining*, the probability of realizing *food-security* increases as the SIS is expected to contribute to a better division of the seeds meant for food production.

6 PHASE 2: PROPOSE A NEW SEED INFORMATION SYSTEM

After the analysis of the context and the current SIS, we propose a context-sensitive SIS in which the identified stakeholder concerns are addressed. To accomplish this, we drew a DM that linked the stakeholder concerns to the SQ concerns (Section 6.1). Based on these concerns and inter-dependencies, we inferred system goals (Section 6.2), functional requirements (Section 6.3), and quality requirements (Section 6.4). Furthermore, we modelled the relation between the requirements and the goals (Section 6.5). Lastly, we describe the status of the current implementation of the SIS (Section 6.6).

6.1 Decision Map of the Proposed Seed Information System

The AOPP plans to scale up the SIS. A main concern of the current implementation of the SIS is that it is not accessible to illiterate stakeholders and stakeholders who do not have access to the internet. Hence, the AOPP is interested in expanding the current SIS with a voice interface to ensure that the SIS is accessible to a wider range of users [7].

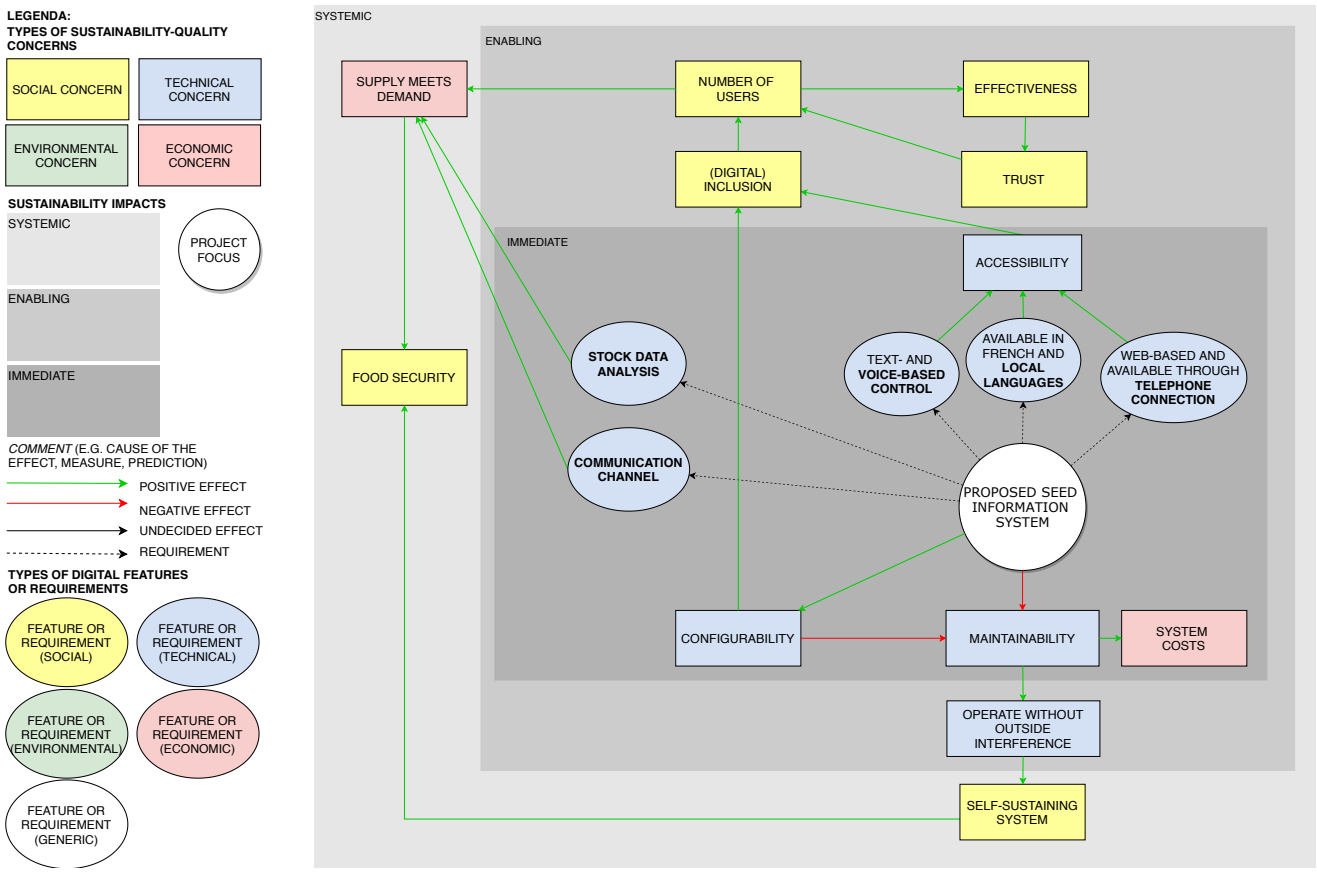

Figure 6 DM that presents the features, sustainability concerns and inter-dependencies of the proposed SIS.

To understand the effects of expanding the SIS with a voice-interface on the SQs, we constructed a DM (see Figure 13 for the DM and Appendix A for the definitions of the used features and SQs). This DM is an extension of the DM of the current SIS which is presented in Figure 5. The DM of the proposed SIS contains extra requirements/features compared to the DM of the

current SIS. The extra requirements/features are: *communication channel*, *stock data analysis*, *voice-based control*, *available in local languages*, and *available through telephone connection*. In the remainder of this section, we explain the expected effects and inter-dependencies of the added features on the SQs.

6.1.1 Communication and Data Analysis

The proposed requirement *communication channel* allows communication between several stakeholders. This requirement is derived from issue I-04 (Lack of communication) (see Table **??**). The AOPP, farmer cooperatives, and other stakeholders experienced poor communication channels as a barrier in the seed value chain [7]. Another proposed requirement is *stock data analysis*. This requirement encompasses the functionalities that allow the seed stock data to be analyzed so that an overview of the current seed stock can be provided, and patterns to predict the future seed stock can be presented. This requirement is based on I-03 (Lack of information). Currently, there is no information available regarding past seed transactions. Hence, the AOPP is not able to provide an overview of the currently available seeds and predict the future demand. These requirements (*communication channel* and *stock data analysis*) have a positive effect on *supply meets demand*. This is due to stakeholder communication allowing the seeds to be more equally distributed. Furthermore, analyzing the stock data allows future planning of seed production as it allows an accurate estimation of seed demand. Hence, if the stakeholders can communicate an excess or shortage of a certain seed variety, it is more likely that the *supply meets the demand*. Currently, it is common that one region has a shortage of certain seeds whereas other regions have the required seeds in stock. The requirements *communication channel* and *stock data analysis* aim to connect regions so that the seeds can be more equally distributed. This is expected to have a positive effect on *food security*.

6.1.2 Stakeholder Access

Other new features of the SIS are the *text- and voice-based control*, *available in French and local languages*, and *web-based and available through telephone connection*. These features are designed to solve accessibility barriers. These new features allow illiterate users, users who do not speak French, and users who do not have access to the internet and/or smart devices to interact with the SIS. Therefore, these features are expected to have a positive effect on *accessibility*. The proposed SIS being accessible to a greater variety of users has a positive effect on *(digital) inclusion*. This allows a network effect to be activated [45]: as more users have access to the SIS, the *number of users* will increase, this has a positive effect on the *effectiveness* as the rise in available seed stock data presents a more accurate overview of the actual available seed stock. If the information in the SIS is accurate, the *trust* of the users increases. In turn, if users *trust* the SIS, they will continue to use the SIS which has a positive effect on *number of users*. Moreover, by adding new features that increase the *accessibility* of the SIS, the SIS becomes *configurable*. This has as main advantage that the SIS has a positive effect on *(digital) inclusion*.

6.1.3 Maintainability & System Costs

The disadvantage of implementing extra features is, however, that the cost of development, operation, and maintenance increases. Hence, the SIS has a negative effect on *maintainability* as the SIS being *configurable* causes the SIS to be more complex and hence requiring more resources to be maintained. These extra resources cause the *system costs* to increase. Furthermore, the SIS being more complex requires extra training for the involved stakeholders. This implicates that the proposed SIS is more difficult to *operate without outside interference* and, therefore, is less likely to be a *self-sustaining system*. If the SIS is self-sustaining, the SIS would have a positive effect on *food security* as the aim of the SIS is to improve the seed value chain. Thus, if the SIS cannot be operated by the local community and resources, the chance of the SIS being sustainable and, hence, being able to have a positive effect on *food security* decreases. Therefore, a business plan is required that outlines how the system can be financed and, hence, sustained over time considering the extra resources that the new features require.

6.1.4 Trade-Off Configurability and Maintainability

When we compare the DM of the current SIS (Figure 5) and the proposed SIS (Figure 13), we observe a clear trade-off between *configurability* and *maintainability*. In order to ensure that the SIS is accessible to all stakeholders, the SIS requires extra features such as voice-based control (i.e. the SIS needs to be configurable). However, adding extra features increases the complexity of

the overall SIS. This causes the SIS to be increasingly difficult and costly to maintain. Hence, the SIS is less likely to be a self-sustaining system. On the other hand, when excluding stakeholders from the SIS, the SIS is not inclusive nor will it gain the required number of users, effectiveness, and trust for it to be a functioning and accurate system.

6.2 Goals of the Proposed Seed Information System

In this section, the goals of the proposed SIS are described (Table 11-18). The goals are derived from the information in [7, 30]. Each goal is documented in a separate table. Every table contains a unique ID to distinguish the goal and a description of the goal. Furthermore, we discuss whether the goal is addressed in the current SIS. Lastly, a link to the relevant requirements (from Section 6.3 and Section 6.4) that aim to achieve the goal is included. These links are visualized and explained in Section 6.5.

Table 11 Inform Farmers

ID	G-01-InformFarmers
Description	The farmers lack information in several parts of the seed value chain, such as: • Places to buy semense de bases • Estimation of quantity and seed variety to produce for next season • Status of quantity sold from current stock • Seed prices • Seed certification process status Hence, the SIS should play a role in informing the farmers and including them in the seed value chain.
Present in the current SIS?	No, currently, the SIS is used by the farmer cooperatives. Involving the farmers in the process is expected to increase their trust in the seed value chain.
Link to requirements	FR-01-InformationBroadcast, FR-03-CertificationStatus, FR-04-LanguageSupport, QR-01-Accessibility, QR-02-Trust, QR-03-Inclusion, QR-06-Maintainability

Table 12 Connect Supplier and Buyer

ID	G-02-ConnectSupplierBuyer
Description	To improve the seed trade, the suppliers and buyers need to be connected. This amplifies faster and an increased number of trades.
Present in the current SIS?	Yes, in the current SIS, farmer cooperatives can fill in stock information and buyers can look up stock information. When the required quantity of a certain grain is in stock, the application displays the contact details of the seller.
Link to requirements	FR-02-VoiceBasedTrade, FR-04-LanguageSupport, QR-01-Accessibility, QR-03-Inclusion, QR-06-Maintainability

Table 13 Connect Regions

ID	G-03-ConnectRegions
Description	Often, the situation occurs that there is a lack of stock in one region and an excess of stock in another region. Currently, the regions have no effective communication channel to communicate their lack or excess of seed stock.
Present in the current SIS?	Partly, the suppliers and buyers from different regions are connected through the current application. However, not all regions use the application. Moreover, the application does not provide an overview of the stock per region.
Link to requirements	FR-05-CommunicationAOPP&FarmerCooperatives, FR-07-Dashboard

Table 14 Communication AOPP and Farmer Cooperatives

ID	G-04-CommunicationAOPP&FarmerCooperatives
Description	Currently, there are many parties involved in the seed value chain. There is a lack of communication between those parties. Especially the AOPP and farmer cooperatives should frequently communicate to support farmers and buyers involved in the seed value chain.
Present in the current SIS?	No, the current SIS does not provide a stakeholder communication channel between the AOPP and the farmer cooperatives.
Link to requirements	FR-05-CommunicationAOPP&FarmerCooperatives

Table 15 Estimate Demand

ID	G-05-EstimateDemand
Description	For farmers to be able to plan the quantity and variety of seeds to be produced for the coming season, the demand should be estimated. Currently, the farmers have issues in estimating the amount of seeds to produce for the next season. Furthermore, the supply and demand are not aligned. If the AOPP could estimate next year's demand, the demand can be communicated to the farmer cooperatives (G-04-Communication) and farmers (G-01-InformFarmers).
Present in the current SIS?	No, the current SIS does not provide an overview of past transactions that allows the prediction of the future demand.
Link to requirements	FR-06-DataAnalysis

Table 16 Overview Seed Stock

ID	G-06-Overview
Description	An overview of the current seed stock aids buyers in understanding which cooperatives have seeds in stock. Furthermore, the AOPP and farmer cooperatives can use this overview to decide how the seed stock can be distributed over the regions.
Present in the current SIS?	No, the current SIS does not provide an overview of the seed stock data.
Link to requirements	FR-07-Dashboard

Table 17 Self-Sustaining System

ID	G-07-SelfSustainingSystem
Description	For the SIS to preserve its functionality over time, the SIS should be sell-sustaining. This entails that the system can be maintained and financed without outside interference.
Present in the current SIS?	The current SIS is hosted and maintained by the AOPP. However, they are still receiving funding from SOS Faim.
Link to requirements	QR-02-Trust, QR-06-Maintainability, QR-07-Sustainability, QR-08-CostEffectiveness

Table 18 Inclusion

ID	G-08-Inclusion
Description	The stakeholders of the SIS are diverse. For the SIS to function, the SIS should include all stakeholders regardless of their skills and resources.
Present in the current SIS?	No, the current SIS solely includes stakeholders that are literate and/or have access to the internet/smart devices. This entails only a small subset of the stakeholders.
Link to requirements	FR-01-Information Broadcast, FR-02-VoiceBasedTrade, FR-04-LanguageSupport, QR-01-Accessibility, QR-03-Inclusion, QR-06-Maintainability

6.3 Functional Requirements of the Proposed Seed Information System

In this section, the functional requirements of the proposed SIS are described. The functional requirements are derived from the DM of the proposed SIS (Section 6.1) and the system goals (Section 6.2). The functional requirement are general, i.e. technical details are not included. Currently, the SIS is extended with an voice interface. Other requirements are recommendations for further extensions. The functional requirements are listed in Tables 19 - 25. Each requirement contains a unique ID, description, motivation, and a link to the relevant goals from Section 6.2.

Table 19 Information Broadcast to Farmers

ID	FR-01-InformationBroadcast
Requirement	The SIS shall broadcast messages, both textual and voice-based, containing information about the seed value chain relevant to the farmers.
Description	Not all farmers are literate and/or are in the possession of an internet connection/smart device. Hence, the farmers have little access to information regarding the seed value chain. Extending the SIS with a radio/voice-interface allows the farmer to receive important information. Examples of messages are: the location of a selling point of semense the bases, estimation of future seed demand, status of quantity sold from current stock, and seed prices.
Motivation	Farmers are currently excluded from the SIS. This decreases their trust in the seed value chain. By informing them, we expect the farmers to gain trust in the seed value chain. Moreover, access to new information aids farmers in selling and producing their seeds.
Link to goals	G-01-InformFarmers, G-08-Inclusion, QR-03-Inclusion

Table 20 Voice-Based Seed Trade Interface

ID	FR-02-VoiceBasedTrade
Requirement	The SIS trade functionality shall be available through a voice interface.
Description	Farmers and/or farmer cooperatives inform the radio station of their seed offerings through a voice-message. This data is manually inserted in the SIS database. Accordingly, the radio station broadcasts available seeds to potential customers.
Motivation	The current trade functionality allows farmer cooperatives to fill in seed stock data together with contact information. The customer can look-up this information through the Android application or website. However, this requires buyers and sellers to be literate and have access to an internet connection/smart device. This is often not the case. For this reason, the SIS is extended with a voice-interface.
Link to goals	G-02-ConnectSupplierBuyer, G-08-Inclusion, QR-01-Accessibility, QR-03-Inclusion, QR-06-Maintainability

Table 21 Status Seed Certification Process

ID	FR-03-CertificationStatus
Requirement	The SIS shall display the status of the certification process.
Description	The seed certification status is displayed in a track and trace manner. This ensures that farmer cooperatives can estimate the waiting time. Furthermore, in case of issues, LaboSem can notify the relevant farmer cooperative.
Motivation	Both farmers and farmer cooperatives often have to wait 3-4 months to receive a certification for their seeds [7]. A track and trace system can provide insight into the current status of the certification. Furthermore, this functions as a communication channel between LaboSem and the farmer cooperatives.
Link to goals	G-01-InformFarmers, QR-02-Trust

Table 22 Language Support

ID	FR-04-LanguageSupport
Requirement	The SIS shall be available in French and local languages (such as Bambara).
Description	Both the textual and the voice messages are available in French and local languages. The user is able to set its preferred language.
Motivation	Currently, the SIS is solely available in French. This excludes stakeholders as not every stakeholder understands French.
Link to goals	G-01-InformFarmers, G-02-ConnectSupplierBuyer, G-08-Inclusion, QR-01-Accessibility, QR-03-Inclusion, QR-06-Maintainability

Table 23 Communication AOPP and Farmer Cooperatives

ID	FR-05-CommunicationAOPP&FarmerCooperatives
Requirement	The SIS shall have an online communication channel in which the AOPP and Farmer Cooperatives can exchange messages.
Description	This communication channel has the form of a forum. In which the AOPP can broadcast information to all farmer cooperatives or target cooperatives of a certain region. Moreover, farmer cooperatives can ask questions to the AOPP regarding, for instance, the working of the SIS.
Motivation	Currently, the AOPP has no efficient communication channel with the farmer cooperatives. Hence, new policies cannot be communicated. Furthermore, farmer cooperatives that run into troubles when using the SIS have no efficient means to receive support.
Link to goals	G-03-ConnectRegions, G-04-CommunicationAOPP&FarmerCooperatives

Table 24 Seed Stock Data Analysis

ID	FR-06-DataAnalysis
Requirement	The SIS shall be capable of analyzing past seed transactions and present the discovered trends.
Description	The analysis of past seed transactions allows the AOPP to estimate the demand. This can be communicated to the farmers which allows the farmers to plan their seed production.
Motivation	To aid farmers in planning the seed production, trends in seed demand need to be discovered. This can be done through data analysis.
Link to goals	G-05-EstimateDemand

Table 25 Seed Stock Dashboard

ID	FR-07D-Dashboard
Requirement	The SIS shall present a map presenting a visual overview of the available seed stock in each area.
Description	The map contains different levels (e.g. Local, Regional). In each level, a color represents the currently available amount of seeds.
Motivation	Currently, the demand and supply of seeds do not match. To cope with the issue of having an excess of seeds in one area and a shortage in another, a visual overview clearly presents in which areas seeds are available.
Link to goals	G-06-Overview, G-03-ConnectRegions

6.4 Quality Requirements of the Proposed Seed Information System

In this section, the quality requirements of the proposed SIS are described. The quality requirements are derived from the DM of the proposed SIS (Section 6.1) and the system goals (Section 6.2). The quality requirements are listed in Tables 26 - 33. Each requirement contains a unique ID, definition, description, motivation, and a link to the relevant goals from Section 6.2.

Table 26 Accessibility

ID	QR-01-Accessibility
Definition	The system can be used by people with the widest range of characteristics and capabilities [26].
Description	The SIS need to be accessible to stakeholders who are illiterate and do no have an internet connection/ smart device.
Motivation	The AOPP is concerned by the fact that farmers and local buyers often cannot access the SIS. Considering that the SIS requires data to function properly, the stakeholders need to access the SIS to fill in the data and retrieve the information.
Link to goals	G-01-InformFarmers, G-02-ConnectSupplierBuyer, FR-05-CommunicationAOPP&FarmerCooperatives

Table 27 Trust

ID	QR-02-Trust
Definition	The stakeholders have confidence that a product or system will behave as intended [26].
Description	The SIS need to show accurate information in order for stakeholders to create trust.
Motivation	The current SIS does not contain accurate information with respect to the seed offerings. This caused users to refrain from using the SIS.
Link to goals	G-07-SelfSustainingSystem

Table 28 Inclusion

ID	QR-03-DigitalInclusion
Definition	Digital inclusion refers to strategies that provide training, services, or opportunities designed to address the challenges of the digitally disadvantaged [46].
Description	The proposed SIS aims to reach the digitally disadvantaged to include them in the seed value chain.
Motivation	The farmers and local customers are essential stakeholders to the seed value chain. Including them in the SIS, empowers these stakeholders and improves the quality of information within the SIS.
Link to goals	G-08-Inclusion

Table 29 Effectiveness

ID	QR-04-Effectiveness
Definition	Accuracy and completeness with which users achieve specified goals [26].
Description	The seed stock data stored in the SIS should reflect the actual seed offerings.
Motivation	Due to a lack of (accurate) data, the current SIS does not reflect the actual seed stock. Hence, stakeholders refrain from using the system.
Link to goals	G-07-SelfSustainingSystem

Table 30 Configurability

ID	QR-05-Configurability
Definition	The ability to modify and extend a system while it is running [47].
Description	The SIS needs to be adjusted to be accessible for: users with and without internet connection, with and without smart devices, with and without digital skills, literate and illiterate, and available in the wide-variety of Malian languages.
Motivation	The SIS has diverse stakeholders, each with their own capabilities and needs. Hence, the SIS needs to be configurable to provide access to all stakeholders.
Link to goals	G-08-Inclusion

Table 31 Maintainability

ID	QR-06-Maintainability
Definition	The relevant attribute of maintainability is modifiability. Modifiability can be defined as: system can be effectively and efficiently modified without introducing defects or degrading existing product quality [26].
Description	The SIS should be maintained by the local community. Hence, the SIS should be modifiable without requiring resources from external parties.
Motivation	The SIS is introduced by external parties. Development aid IT projects often cease to exist once the funding stops.
Link to goals	G-07-SelfSustainingSystem

Table 32 Sustainability

ID	QR-07-Sustainability
Definition	(In this context:) To preserve the function of a system over an extended period of time [3].
Description	The SIS needs to keep performing over an extended period of time.
Motivation	The SIS aims to contribute towards food security. This is a long-term goal and can only be achieved if SIS keeps performing over time.
Link to goals	G-07-SelfSustainingSystem

Table 33 Cost-Effectiveness

ID	QR-08-CostEffectiveness
Definition	The benefit of the SIS is good relative to the amount of money paid[6].
Description	The SIS should be financed by the local community using local resources.
Motivation	The development, operation, and maintenance of the SIS are constrained by a budget. Currently, the SIS is financed by SOS Faim. However, this is a temporary construction to introduce the system to the users so that they understand and experience its purpose and benefits. After the stakeholders are convinced of the working of the SIS, they are expected to contribute in financing the SIS.
Link to goals	G-07-SelfSustainingSystem

6.5 Overview Goals, Functional Requirements, and Quality Requirements

This section provides an overview of the goals, functional requirements, and quality requirements of the proposed SIS. We start by providing a visual representation of the relation of the goals and functional requirements (Section 6.5.1). Afterward, we show the expected effects of the goals and functional requirements on the quality requirements (Section 6.5.2).

6.5.1 Relation Goals and Functional Requirements

In this section, we present a visual overview of the goals and functional requirements of the SIS. This allows the reader and stakeholders to understand the concrete implementation of the abstract goals. The diagram and legend are shown in Figure 7. The notation of the diagram is inspired by the notation of the DM (see Section 3.2). We extended the notation of the DM by diamonds that represent stakeholder goals. These goals are classified in the social, technical, environmental, and economic dimensions. We chose to extend the DM to create unity in the used diagrams within this study.

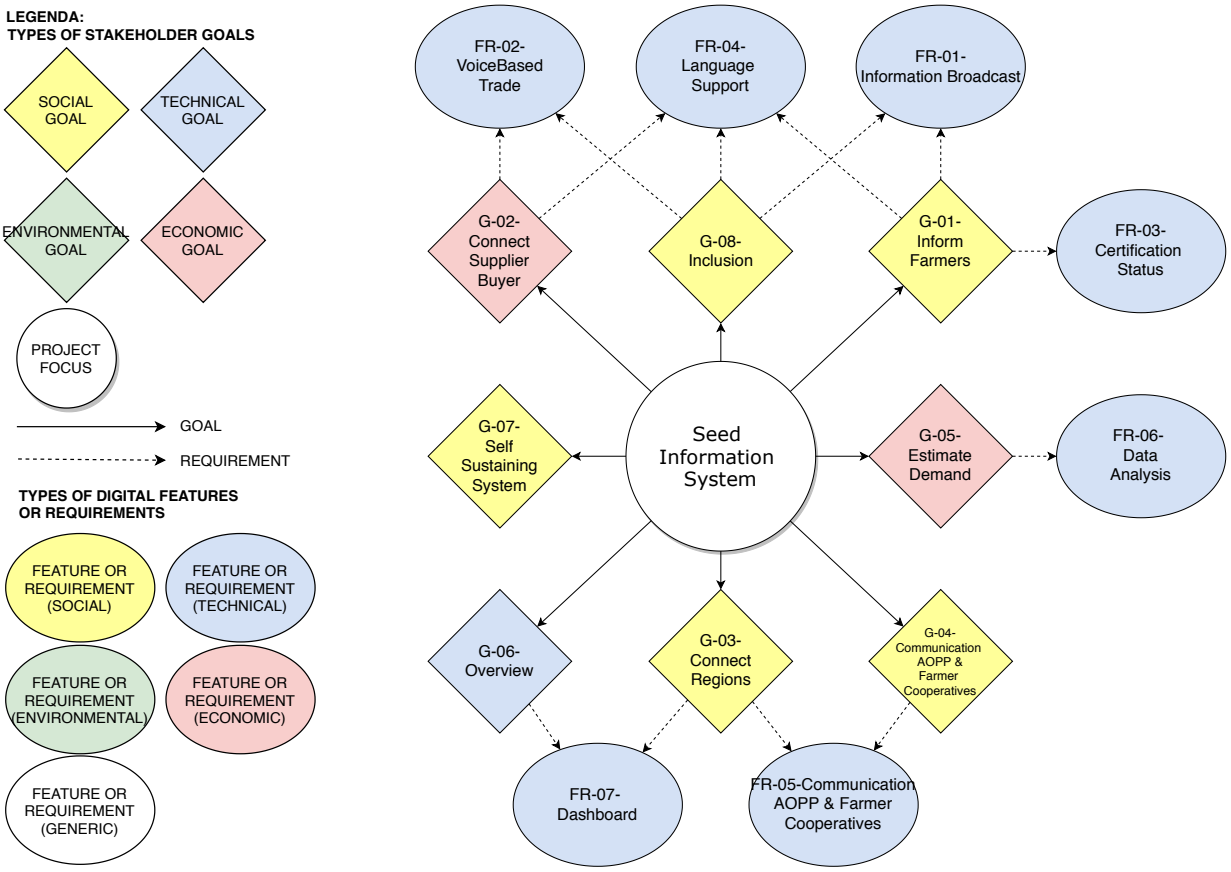

Figure 7 Overview of the goals and functional requirements of the SIS.

In Figure 7, the proposed SIS is placed in the center as it is our project focus. The goals that are described in Section 6.2 are connected to the SIS. Each goal, is linked to the requirements (from Section 6.3) that aim to realize this goal. We discuss the goals and relation to the functional requirements from left to right as presented in Figure 7.

G-02-ConnectSupplierBuyer is implemented by *FR-02-VoiceBasedTrade* as the voice-based service allows communication between the suppliers and buyers of the seed value chain. The goal is also implemented by *FR-04-LanguageSupport* as the support of multiple, local languages allows access to the SIS for more farmers and farmer cooperatives. This results in improved trade as more suppliers and buyers can be connected.

[6] dictionary.cambridge.org/dictionary/english/cost-effective

G-08-Inclusion is realized through three functional requirements. First, *FR-02-VoiceBasedTrade* realizes inclusion as by voice technology illiterate stakeholders without access to smart devices and an internet connection can access the SIS. Second, *FR-04-LanguageSupport* ensures that stakeholders that speak local languages are included in the SIS. Last, *FR-01-InformationBroadcast* allows farmers to be included in the seed value chain. Currently, most farmers are excluded from the seed value chain processes [7].

G-01-InformFarmers is implemented by *FR-04-LanguageSupport* as this requirement states that local languages should be included in the SIS. Considering that most farmers do not speak French, this requirement realizes more farmers to have access to relevant information regarding the seed value chain. Next, *FR-01-InformationBroadcast* aids in informing farmers as the (radio) broadcast functionality reaches more farmers. Especially in the rural areas in which farmers do not have access to the internet. Finally, *FR-03-CertificationStatus* informs farmers as a frequently mentioned bottleneck in the seed value chain is the long waiting time to receive a certification of the seeds [7]. An extension of the SIS that shows the status of the certification process aids farmers in selling their (certified) seeds.

G-07-SelfSustainingSystem is a goal that is not implemented by requirements. The nature of the goal is more related to the quality requirements and shall therefore be discussed in Section 6.5.2.

G-05-EstimateDemand aims to aid farmers in understanding the amount and variety of seeds to produce for the next season. This can be achieved by implementing *FR-06-DataAnalysis* to understand trends and patterns in the seed demand.

G-06-Overview aims to provide an overview of the current seed stock. This can be implemented by *FR-07-Dashboard* as this is an intuitive tool to summarize the stock per area/region.

G-03-ConnectRegions is implemented by *FR-07-Dashboard* as the seed stock per region can be visualized. This allows representatives or traders from a certain region to look up whether other regions can offer seeds that match their requests. Next, *FR-05-CommunicationAOPP&FarmerCooperatives* ensures that the AOPP can communicate with the farmer cooperatives of the several regions. This allows the AOPP to support the regions in fairly distributing the available seed stock.

G-04-CommunicationAOPP&FarmerCooperatives is essential to realize the adaption of the SIS as the AOPP can motivate and explain the SIS to the farmer cooperatives. This is implemented by a communication channel described in *FR-05-CommunicationAOPP&FarmerCooperatives*.

6.5.2 Impact on the Quality Requirements

In the previous section, the quality requirements are not included in the diagram to keep the diagram understandable and focused. In this section, we zoom into the goals and functional requirements that are expected to have a direct effect on the quality requirements. The quality requirements are inferred from the SQ concerns. This results in diagrams that link the goals (Section 6.2) to the functional requirements (Section 6.3) and quality requirements (Section 6.4). The relation between the goals and the functional requirements is explained in Section 6.5.1. The effects on the quality requirements are difficult to measure as these are not observable by objective metrics. Furthermore, the SQ concerns have many interdependencies (e.g. if the system is difficult to maintain, the system costs are expected to rise). In this section, we merely focus on the direct effects on the quality requirements. The interdependencies between the quality requirements are visualized in the DM (see Section 6.1).

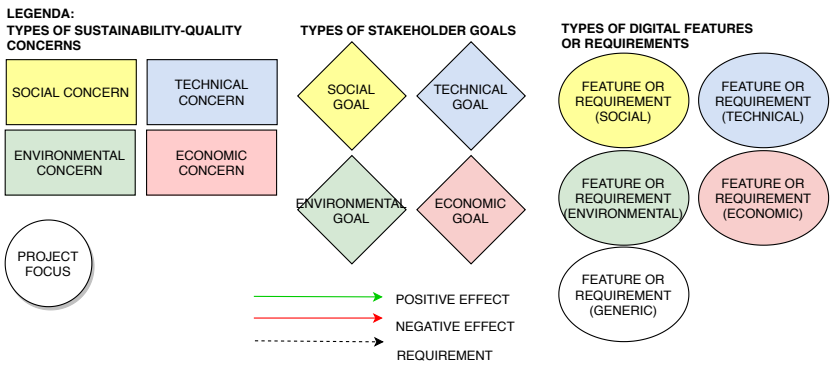

Figure 8 Legend of the goal, functional requirement, and quality requirement diagrams.

The notation is inspired by the Questions Options Criteria (QOC) modelling technique [19]. This is a technique that allows exploring several options to accomplish a goal by analyzing its effect on several quality criteria. In this study, we translated the options to functional requirements and the quality criteria to quality requirements. This allows readers and stakeholders to understand and communicate about the expected effects of the functional requirements on the quality requirements. The visual representation of the diagrams is inspired by the notation of the DM (Section 3.2). This notation of the DM is extended with a diamond that represents stakeholder goals (as introduced in Section 6.5.1). The legend of the used notation is presented in Figure 8.

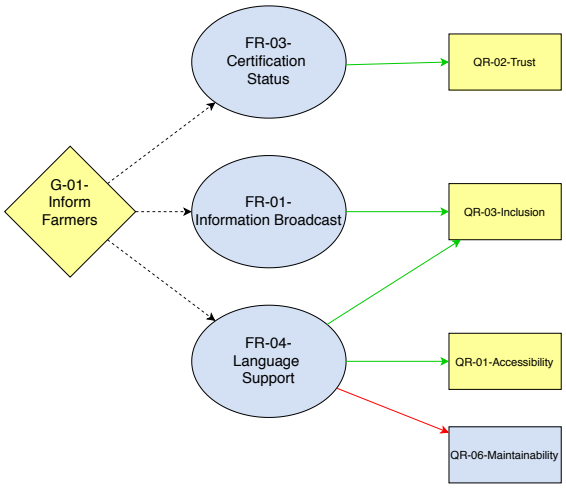

Figure 9 Impact of goal *G-01-InformFarmers* on the quality requirements.

Figure 9 represents the relation between the goal *G-01-InformFarmers* and the functional requirements: *FR-04-LanguageSupport*, *FR-01-InformationBroadcast*, and *FR-03-CertificationStatus* combined with the impact on the quality requirements *QR-O2-Trust*, *QR-O3-Inclusion*, *QR-O1-Accessibility*, and *QR-O6-Maintainability*. *FR-03-CertificationStatus* has a positive effect on *QR-O2-Trust* as the farmers currently do not have access to the certification status of the seeds. Including the farmers in this process is expected to increase their trust [7]. *FR-01-InformationBroadcast* is expected to include farmers in the seed value chain by informing them about stock offerings and seed plans. Hence, the farmers are included in the information flow and this explains the positive effect on *QR-O3-Inclusion*. Last, the functional requirement *FR-04-LanguageSupport* introduces translations of the SIS to local languages. This has a positive effect on the *QR-O3-Inclusion* and *QR-O1-Accessibility*. However, adding multiple system version has a negative impact on *QR-O6-Maintainability*.

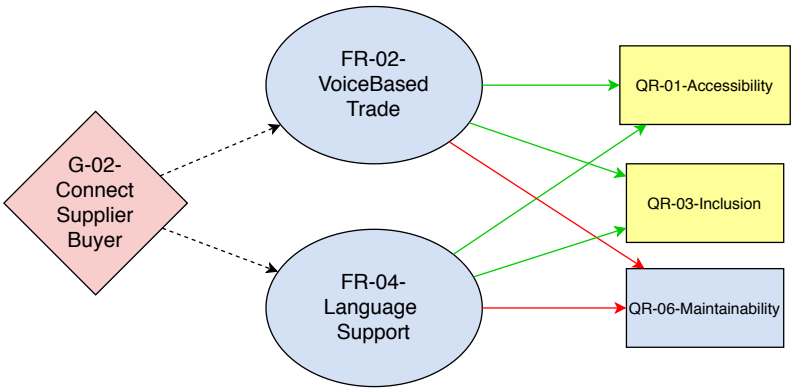

Figure 10 Impact of goal *G-02-ConnectBuyerSupplier* on the quality requirements.

Figure 10 represents the relation between the goal *G-02-ConnectSupplierBuyer* and the functional requirements *FR-02-VoiceBasedTrade* and *FR-04-LanguageSupport* together with the effects on the quality requirements *QR-O1-Accessibility*, *QR-O3-Inclusion*, and *QR-O6-Maintainability*. This diagram visualizes the previously mentioned trade-off between Accessibility and Maintainability. By introducing new system features (such as voice-based control and language support) more stakeholders have access to the SIS. However, the increased system functionalities have a negative effect on the *QR-O6-Maintainability*.

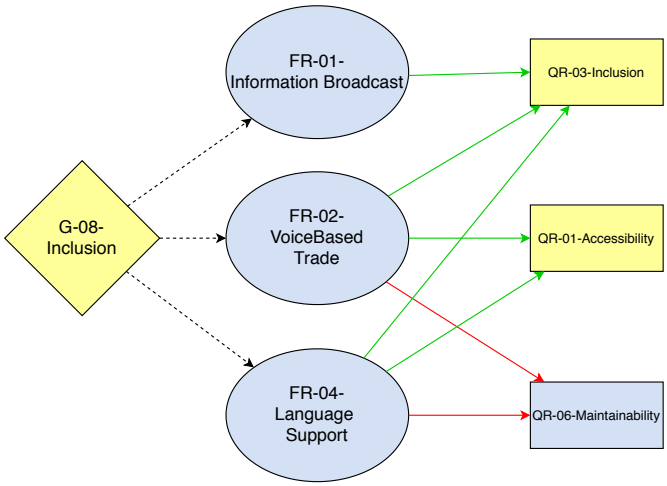

Figure 11 Impact of goal *G-08-Inclusion* on the quality requirements.

Figure 11 shows the relation between goal *G-08-Inclusion* and the functional requirements *FR-01-InformationBroadcast*, *FR-02-VoiceBasedTrade*, and *FR-04-LanguageSupport* together with the effects on the quality requirements *GR-03-Inclusion*, *QR-O1-Accessibility*, and *QR-O6-Maintainability*. This visualizes that inclusion (realized through information broadcasts, voice-based trade, and language support) improves the accessibility by including more stakeholders in the seed value chain. However, this has a negative effect on maintainability as the scope and size of the SIS increases.

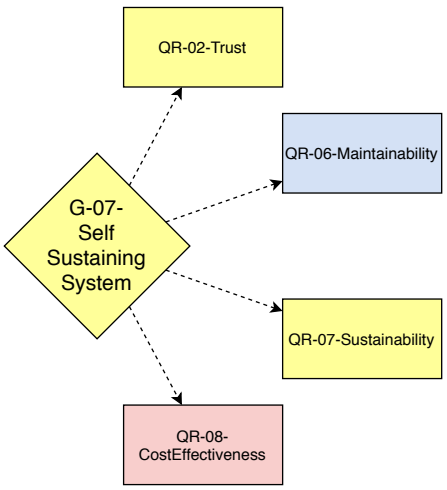

Figure 12 Impact of goal *G-07-SelfSustainingSystem* on the quality requirements.

Last, in Figure 12 we discuss the goal *G-07-SelfSustainingSystem*. This goal is different compared to other goals as there are no concrete functional requirements that implement this goal. Having a self-sustaining system involves that the local community is

able to operate and maintain the SIS with local resources and without outside interference. This can be realized by having a system that (1) the users trust and therefore use (*QR-02-Trust*), (2) the local community is able to maintain (*QR-06-Maintainability*), (3) is sustainable within all sustainability dimensions (*QR-07-Sustainability*), and (4) adds value and is affordable relative to its investment and operation costs (*QR-08-CostEffectiveness*).

6.6 Implementation of the Seed Information System

The AOPP plans to extend the SIS with a voice-interface [30]. Currently, SOS Faim and SIDI[7] are funding the development. We interviewed André Baart, who is implementing a prototype of the voice-based application that connects traders and customers of seeds. In this section, we provide an overview of the implementation and vision of the SIS based on this interview.

6.6.1 Prototyping the Voice-Interface Service

The developers of the voice-interface service to extend the SIS are currently designing a prototype. This prototype allows customers to query seed offerings through a telephone line and receive a voice-based response. The main goal of this service is to match the seed supply and demand. The implementation of a prototype allows a targeted discussion with users to obtain feedback about the service. If the users are positive about the service, the developers continue to extend and improve the prototype in further iterations. The development of this voice-interface is radically different compared to common development processes as it targets users without internet and smart devices. This imposes limitations on the way users interact with the systems and hence the number of supported functionalities. Moreover, the interface is required to be simplistic to be understandable by users that are illiterate.

The goal of the first version of the prototype is to realize a service that allows farmers query seed stock data using their simple cell phone. Consequently, the service returns a voice-message with locations that have this seed request in stock. The users often have no experience with search menus, hence, it is essential to create a simplistic user-interface. The required data that the users need to insert are their location, the requested amount of seeds, and their requested seed variety. After this, the system returns current stock information relating to the query. In the current prototype, the data has to be typed in using the phone keypad. This is not ideal for the (illiterate) target audience. However, as there are solely a few data points, the functionality can be made intuitive. An alternative would be to let the users record a voice message containing their location and seed request. However, this imposes several challenges as speech detection and natural language processing techniques are not mature enough for Malian languages. This holds for basically every native African language, except perhaps Swahili. These languages are referred to as “under-resourced languages". Another option is to hire a translator who listens to the recorded voice messages of the users and types in the request manually. This approach is costly and will slow down the process. These alternatives can be further elaborated in a later stage of the implementation. For now, the prototype needs to be simple in order to receive user feedback early on in the development process.

The prototype returns a voice message containing the location of the cooperatives that have the requested seeds in stock. This message will be automatically generated by a computer voice in French. This prototype iteration does not support local languages. If this iteration results in positive feedback, a future iteration could utilize pre-recorded voice messages by a translator for the system to be able to return voice messages in Bambara.

The developers are in an early stage of the development process. They involve the stakeholders regularly in this process to understand their needs and receive feedback on the service. The stakeholder responses are overall positive. However, the developers are a bit wary of potential wishful thinking. Currently, the concept might be too abstract to receive useful feedback. It is common that users do know their exact needs. Hence, the developers use the prototype to get a deeper understanding of the user requirements. To evaluate the service, the developers and researchers evaluate whether the user sees it as beneficial and are willing to pay for it (e.g. the telephone minutes). Eventually, the AOPP will evaluate the service. This would be a major indication of whether the SIS will continue to be developed and improved.

6.6.2 Relation to the current SIS

This first prototype will initially not be connected to the current SIS. The current SIS is completely text-based, hence, to be of use its content should be translated to speech. This is a time-intensive and costly process. Hence, the developers aim to understand

[7] www.sidi.fr

which components will actually be used prior to translating all the information within the current SIS. Eventually, the aim of the SIS is to couple all the data to the same database which can be accessed through various interfaces such as the telephone service but also through the currently available web-interface.

6.6.3 Collaboration with Radio Stations

Radio stations can support in promoting the voice-based SIS and provide users with instructions. The developers and researchers of the SIS work closely together with local radio stations who are willing to collaborate. Furthermore, the radio stations could support by broadcasting seed offerings within a region.

6.6.4 Internet Transition in Mali

An important concern that needs to be addressed is whether the rise of internet technology in Mali will make the voice-interface redundant. In other words: will it be beneficial to invest resources in the development of a voice-interface when an internet transition can cause the service to be useless? In Mali, internet access is increasing. However, this is mainly in the urban rather than the rural areas [48]. The target audience of the voice service are farmers in rural areas and in this group, the literacy rate is still relatively low [49]. Hence, even if the digital infrastructure will improve, video- and voice-based applications are predicted to remain useful for the illiterate stakeholders. Smartphones can be used without being able to read and write, however, for such applications, a high bandwidth and stable connection are required. Hence, the developers foresee that it is useful to extend the SIS with a voice-interface.

6.6.5 Sustainable Business Model

The vision of the researchers and developers is to fund the R&D process using support from development organizations and accordingly deliver affordable/free voice technology to local businesses. This allows local companies to develop small applications targeted to support local business processes such as the seed value chain.

Developing the prototype from Europe is inefficient and causes the development process to be unsustainable for the local market. For instance, in the testing phase, the developers utilize an international telephone number to use the voice-interface. This is required in order to operate the SIS from Europe. Moreover, the costs of external developers are disproportionate to the local economic standards. The only way the project will be feasible in the long term is when local developers can maintain the SIS. Eventually, the services need to be implemented locally to create a sustainable situation.

The R&D budget is not sufficient to scale up the project over the entire country. The researchers and developers start by evaluating whether the SIS serves the needs of local users and stakeholders. If so, a local business needs to be founded to scale and sustain the SIS.

6.6.6 Trust Requires Time

Another trend that the researchers and developers observe is that the feedback on the SIS initially was predominantly negative. However, after some time they noticed an increase in trust. Recently, traders mention an increase in sales due to the SIS. Often, when new systems are being introduced, the users resist as it is complicated and expensive to change habits. At a certain moment in time, a swift can occur as users realize the benefit of a system. The lesson learned here is that sometimes an implementation should not be classified as a success or failure to early on after its release. A system needs to adapt to its environment and vice versa.

7 PHASE 3: ETHICS

To gather insight in how ethical considerations could be incorporated into ICT4D projects which acknowledge cultural diversity, we conducted interviews with experts in the fields of ICT4D and ethics. We aimed to interview experts with various cultural backgrounds to gather perspectives that where not colored by one specific culture.

We conducted semi-structured interviews [50] in which certain themes were discussed using open-ended questions. Due to a variety of backgrounds, both culturally and professionally, often more explanation was needed for participants to understand the

questions. In some instances, examples had to be provided to make a question less abstract. The interview protocol, including offered examples and explanation, can be found in Appendix B.

We then transcribed the interviews using paraphrasing. After transcription, interviews were analyzed and the paraphrased answers to each theme are presented in 7.1. We then analyzed data collected for each theme and compared the views of each interviewee to gather general notions. After the analysis, we applied the general notions to the Mali seed project context. During this application, we looked at how their recommendations could fit in the context of this project or whether the recommendations were already applied. We reflected on the interviews and linked them to existing literature. From this, we derived ways to incorporate ethical considerations into ICT4D projects. Lastly, we integrated the ethical reflections into the DMs.

Section 7.1 gives an overview of the selected interviewees and reports the main findings for the respective themes, as mentioned by each interviewee. In section**??** ✎ Hella: finish the overview of the sections

7.1 Interviews

We conducted four semi-structured interviews with people from different cultural backgrounds, who are experts in the fields of ethics, technology and ICT4D. In these interviews, four themes were discussed (see appendix B), namely (1) Cultural background and context of the interviewee; (2) Foreseen challenges of fast developments in the field of technology; (3) Embedding ethics in the context of the interviewee; and (4) How to address value clashes due to cultural differences in the design process of an ICT4D project.

7.1.1 Interviewees

The four selected interviewees (I1, I2, I3, I4) are listed below including their professional background and their country of origin.

- I1: Expert in the field of human rights, from Zimbabwe
- I2: Expert in the field of moral reasoning and AI, from India
- I3: Expert in the field of ICT, entrepreneurship, and gender, from Ghana
- I4: Expert in the field of ICT4D, from Malaysia

7.1.2 Themes

The four discussed themes and the corresponding (paraphrased) views of each interviewee are explained below.

Theme 1: Cultural background and context of interviewee

I1: Expert in the field of human rights who is interested in cultural sensitivity in the context of human rights.

I2: Expert in the field of moral reasoning and AI, from India. She has a background in economics with an interest in the philosophical side. When exploring the philosophy of economics, she became interested in moral philosophy and how this could be used to understand and talk about a wide variety of major issues, such as climate change and the implications of AI.

I3: Started a company in Ghana which focuses on supporting businesses to establish applications and web-based solutions that solve their problems. She became interested in technology when she noticed how it could empower people and she wanted to share this power she felt by educating and supporting others in the world of the internet.

I4: He became interested in ICT4D through the poverty and inequality he saw around him in Malaysia. He joined a center of excellence in which people from different disciplines come together to make technology and the internet accessible to a wider public.

Theme 2: Foreseen challenges of fast developments in the field of technology

I1: It is difficult to predict what will happen, but a bottom-up approach could prevent negative implications of development. By talking to the grassroots a light could be shed on blind spots and unwanted consequences can be prevented.

I2: The general attitude towards notions such as AI is that it is potentially very dangerous and will take over our lives. I think this is unrealistic. I do however worry about the fact that technology tends to develop in sudden leaps which can be unexpected. If we are not careful and not taking ethics into consideration, we could find ourselves in dangerous situations. An example is autonomous weapons, which can be extremely hazardous.

I3: The advantages greatly outweigh the disadvantages of technology, but it can do harm. People can use technology to do bad things. People can hide their identity for example, and stalk people online, children can easily find things they are not supposed to see. As a parent, I have to monitor the internet use of my children, because they can find things that can be harmful.

I4: Notions such as AI are fairly unknown in Malaysia, so not much discussion has taken place in Malaysia. I do think it is important to consider ethics when such technology is concerned, but I think for now it is something far from the communities. In Malaysia, we should first focus on actually building such a system before ethics can come into play.

Theme 3: Embedding ethics in context of the interviewee

I1: Researching how human rights can be more tailored to the local situation.

I2: In AI we see that it can behave very misogynistic and abusive because it learns from the environment. That is what we are trying to rectify.

I3: People are becoming more and more concerned with privacy. So that is something we are concerned with, how to communicate to the end-user which data is collected and by who. We saw that in the beginning, people were not very concerned with who had access to their data, but when certain content started showing up and they started receiving certain messages, they wondered where they had shared this data.

I4: I think ethics should be taken into account more in the context of Malaysia. There are many ethnic groups with their own customs and values. But people are not very concerned with things such as copyright and privacy. Right now they say that we are in a crisis because of the coronavirus, so no need to talk about data, just take it, we want to survive.

Theme 4: How to address value clashes due to cultural differences in the design process of an ICT4D project

I1: An ICT4D project should always be culturally sensitive, having money does not give funding partners the right to impose ideas. By addressing the grassroots and let ideas come from them, you prevent imposing an idea on them. When you have to explain concepts that they do not understand, such as data privacy, you should relate these to local concepts and use analogies. When a clash occurs, you should try to strike a balance. . Find a balance between the global and the local—glocalization that is to say product or service that is developed and distributed globally are also adjusted to accommodate the user or consumer in a local market.

You should also need to teach people and update their knowledge. You need to tell them about respect for privacy for example, but always in the language understood by the locals. If you bring in new concepts such as this, always use the language that is understood by the locals.

I2: This is very difficult. Value clashes such as concerning gender equality, are often related to education. To people with higher education, gender matters a lot. They see the value of gender equality. People without this education do not look at it along those lines. We reach them by including the women that are thinking about gender equality. That will start the conversation and then you can convince them of gender equality.

I3: It is important to come to involve people in the process, that way you can overcome blind spots you might have because you never really know someone. When you actively involve people, they will be more likely to adopt your application in the end. If a clash occurs, you should come to some sort of understanding. Explain the benefit of that option. Share the benefits of said values and how it will collectively ensure the project will be a success. You prevent to be paternalistic as a developer by explaining why your ideas are important. Concerning gender equality, for example, you could explain it would affect the project if some are excluded.

I4: You really need to understand their culture, and if there is a clash, you should not want to change too fast. Educating should always happen in their own language. But I have never noticed any clash in cultures in my own experiences with ICT4D projects. What we propose, they will try, but will not always adopt in the end.

7.1.3 Results

In this section, the views of each interviewee are compared and analyzed for the respective themes.

Theme 1: Cultural background and context of interviewee

The interviewees have different backgrounds ranging from ICT to human rights and ethics. Their cultural backgrounds also differ due to the selection of participants. We interviewed experts from Zimbabwe, India, Ghana, and Malaysia.

Theme 2: Foreseen challenges of fast developments in the field of technology

The general attitude of all interviewees regarding possible challenges of fast development in the field of technology was fairly optimistic. I1 mentioned that, regarding developmental work, talking to grassroots could help prevent unwanted consequences of implementing technology. I4 mentioned that Malaysia is behind in the development of technology, so the fear of negative consequences due to AI, for example, is not present at the moment. I3 mentions that technology can be harmful, mainly concerning privacy, but that positive consequences greatly outweigh negative consequences. I2 remarks that the fear and science fiction stories about AI are exaggerated. She does however mention that technology tends to progress in big leaps, causing ethical consideration and legal framework to fall behind. This could cause dangerous situations if we are not careful and take ethics into account.

Theme 3: Embedding ethics in the context of the interviewee

Not all interviewees embedded ethical consideration into their work in either ICT or ICT4D projects. I4 mentioned that, although ethics would be lucrative to use in the context of the variety of ethnic groups in Malaysia, it was not something people are concerned with. He mentioned especially copyright and privacy, with which people are not very concerned. Although I2 mentioned that she saw people in the fields of AI, making ethical considerations, this happened after the negative consequences had already taken place. The AI which was studied showed misogynistic behavior, which developers tried to rectify. I3 sees in her company in Ghana which supports developers, that users are becoming more and more concerned with their privacy. So that is something they are increasingly concerned with, how to communicate to the end-user how their data is collected and by who.

Theme 4: How to address value clashes due to cultural differences in the design process of an ICT4D project

The interviewees had several recommendations on how to address cultural differences between developer and user in the design process of an ICT4D project. First of all, I1 and I4 mentioned that you should understand their culture. I1 stresses that the project should be culturally sensitive. The funding partners do not have the right to impose ideas, but these ideas should come from the grassroots. All interviewees mention that you should talk with potential users to understand them better.

Concerning value clashes that could arise due to said cultural differences, the interviewees had various solutions. Most mentioned the need to come to an understanding. I3 explained this further by establishing that there is a common goal: the success of the project. Relate this goal to you value and how adhering to this value could reach the goal. An example she gave, concerned gender equality. The goal of the project is to reach a wide public, if women are harder to reach due to gender inequality, there should be a focus on them to ensure to goal to include as many people as possible. Although most interviewees mentioned the need to strike a balance, they also mentioned the need to educate the community. They say value clashes occur due to a difference in education. I2 for example, mentions that gender equality is important to those with higher education, because they see the benefits. If gender equality causes a value clash, these benefits must be showed to the potential users. I1 mentions that sometimes people do not see the importance of data privacy. They must be taught about his using concepts that can be related to concepts they know. I4 mentions that he never encountered a value clash in his ICT4D work. He does mention that people sometimes do not adopt the systems they develop together. Lastly, most interviewees mention the importance of communication in the language of the potential users.

7.2 Application to the Mali Seed Context

In this section, the views of the interviewees are applied to the Mali Seed project. We describe, using examples, whether requirements mentioned in the interviews were met.

7.2.1 Language

In the interviews severally notions were mentioned, which the interviewees deemed necessary for facilitating ethical consideration in an ICT4D project. First of all, the need to communicate in the language of the potential user, not only in the design process but also the application needs to address the user in this way. This is considered to be the basis for a conversation in which values of both parties (developer and community) can be voiced, so inclusion of the community in the design process can take place.

In the Mali Seed project, such communication has taken place. The developers made use of co-creative workshops in which discussions took place in the local language, Bambara. After each discussion, an intermediary provided a summary in french. Vice versa, french, spoken by the researcher was simultaneously translated into Bambara. Facilitating a discussion in the local language ensured inclusion of the community in the design process. [15]

Making the Seed Information system accessible in Bambara as well, ensured that individuals could access the system themselves and were aware of their participation in the project. The farmer association mentioned, however, that literacy could be an issue for some farmers, so a voice interface [12] is being developed to make the information system accessible for those who are not sufficiently literate.

7.2.2 Starting with the Grassroots

Another prerequisite, as mentioned by the interviewees, to establish ethical consideration in the design process, is being culturally sensitive. This was described as listening to the community and not imposing your own ideas. In the Mali Seed project, the approached the researches at VU Amsterdam to talk about possible ICT solutions in their daily work. The idea for building a Seed Information System, therefore, came mainly from the farmers themselves [15]. The researchers proposed proposed to built this system and found help in an outside organisation, SOSFaim, who funded the project. Letting the future user community set up the project themselves, creates the potential to be culturally sensitive, for the community can implement what they deem fit.

7.2.3 Striking a Balance

Another notion which all interviewees agreed upon was the need for striking a balance or coming to an understanding in the case of a value clash. A concrete example is the importance of gender equality. What this entails and the level of importance, varies between cultures. In Mali, women and men in agriculture tend to work separately, both women and men have their own land which they cultivate. However, at the start of the co-creative workshops with farmers associations, women where underrepresented [7].

A prerequisite of the donor agency Nuffic [8] is that men and women are equally represented in the projects. In the context of Mali, this was a difficult goal to achieve due to cultural differences. One could argue the cultural sensitivity of such a claim made by the donor agency. To meet the prerequisite, however, women were invited to join the brainstorm and interview sessions for the Seed Information System. During the meetings, the men felt outnumbered by the women, who where more vocal in the voicing of their opinions. This resulted in a skewed representation. It was then decided to split the groups according to gender and continue the meetings in this way. Both groups now felt free to voice their opinions and participate [7]. One could see in this example how a value clash has been addressed in the Mali Seed Project. At first the community was hesitant to include women in the project. The funding organisations however, considered gender equality as an important notion which needed to be addressed. The community met this prerequisite and invited women to the meetings. When it turned out to be an unproductive arrangement, groups were split, so measures that ensure gender equality where more tailored to the local context. This shows how you can come to an understanding in your collective aim to ensure the success of the project.

7.2.4 Data Protection

Privacy and the need for data protection was often mentioned in the context of ICT projects. When people do not value this as much as the developer, the developer should educate the community about its importance, was the general consensus of the interviewees. In a similar project to the Mali Seed project, the RadioMarché Project [51] such a disagreement has also taken place. Education on the need for data protection was, however, not provided. The farmers were asked how they would want to be represented in the database and what data they were willing to provide. They wanted their phone numbers, pictures and addresses to be mentioned, for they saw it as a marketing strategy, they were entrepreneurs after all, (see interviews [9]. The developers

[8] https://www.nuffic.nl/en/subjects/orange-knowledge-programme/call-joint-proposals-tailor-made-training-tmt-orange-knowledge

[9] https://w4ra.org/interview-with-zakary-diarra-beekeeper-in-mali/) and https://w4ra.org/naomi-dembele-bianivo-mounkoro-and-anna-bon-about-agro-forestry-value-chains-in-mali/

adhered to their wishes, but breached later stricter regulations concerning privacy and data use. They should have protected their privacy against their wishes, as that is what a developer should do. This is a difficult dilemma. On the one hand, you want to protect your users, but on the other hand, you do not want to be paternalistic. These farmers gave valid reasons to share their data, overruling this would mean you know better than they do what is good for them. The researchers explained their actions by mentioning that both parties, the farmers and themselves, were equal partners, who deliberated and came to a agreement.

7.3 Reflection

In this section, we reflect on the recommendations of the interviewees how ethical consideration can be an inherent part of ICT4D projects. We noticed that a participatory approach can be used as a tool to meet the requirements as mentioned by the interviewees. Lastly, we mention issues which did not come up during the interviews but should be addressed when attempting to set up ethical projects.

7.3.1 Education as the Solution to Value Clashes

From the interviews, some general sentiments can be drawn. Firstly, almost all interviewees noted, after asking follow-up questions, that in the case of a value clash, education is needed. They mentioned, when developer and future user community do not agree on good practise (e.g. including women/data protection) during the design process, often differences in education is the underlying issue.

The focus of the interviewees on education seems to contradict their emphasis on cultural sensitivity. On the other hand, they stress the need for developers to open themselves up to the other culture and try the understand them. On the other hand, they signify that often a value clash is due to a difference in education. To rectify this, they say the developer should educate the community in the benefits of their values. In the case of gender equality, they could stress the benefits of including a diverse group of people in the project.

This need for education, provided by the developer is a notion which often recurred in the interviews. You could argue this cannot be associated with cultural sensitivity, for the differences in values is attributed to a lack of knowledge instead of a difference in culture. Phillipa Foot [24] demonstrates in her essay on cultural relativism that different cultures can have different ethical judgement. She does, however, rightly show that relativism of cultures has to stop somewhere. She does not indicate where to draw this line, rather, she acknowledges that one can feel a certain level of agreement on the issues that are truly important.

Aiming to solve value clashes by means of more education could indicate a feeling of superiority of your own values. By honouring this feeling, paternalism occurs, where developers act as if they know what is best for a community. Fostering such an attitude can have several detrimental consequences. Firstly, the success of the project could be at stake. History has shown that failing to tailor interventions to the local context often does not promote the success of said intervention [5]. On top of this, imposing ideas on others could reduce the willingness of the community to cooperate and adopt the developed technology. Secondly, paternalism denies the existence of a plurality of right actions.

While it is difficult to come to an agreement whether advocating for education on your own values is paternalistic, it does lead us to an important realisation. It shows us how rigidly individuals tend to hold on to their own ideas. The participants who were interviewed did not conclude that their differences of opinion might be due to cultural differences and should therefore be honoured. The authors, on the other hand, questioned the need for education and argued, in these hypothetical situations, that values of the community should be leading. This disagreement shows us that there are multiple views on this issue, and this underlines the difficulty of trying to be culturally sensitive without foregoing your own values. How to balance these two notions is difficult, but a developer should be aware of this tension.

7.3.2 Co-Creation as a Tool to Incorporate Ethical Considerations

During the interviews, an emphasis on deliberation and dialogue was seen to address the issue of cultural differences which can blur the right course of action. The iterative process of an ICT4D project, such as the Mali Seed Project, has this deliberation and dialogue built in. It seems like approaching the design process in such a co-creational way, leaves room for ethical consideration. As mentioned by Grosz et al. [25], no single moral theory, or list of principles can guide a developer to the right action. Not only because a different situation calls for a different approach, but also because no single right action exists, for cultures can be directive in what constitutes as a right action [24].

While no outside authority or moral theory can objectively state what the right course of action in this specific situation is, a deliberative approach is needed. Co-creational design has a deliberative approach built in and could therefore provide room for ethical consideration. In co-creation, the aim is to collectively build a sustainable system which adds value to peoples lives. The aim is to add value, while refraining from doing harm in other areas. What constitutes as harm and what constitutes as adding value, can differ between developer and community, and even within a community or group of developers. A dialogue can aim to help people be open for the views of others and come to an understanding. Both parties have the same goal, the success of the project, dialogue can help work towards this.

7.3.3 Problems That Remain

Although co-creation, has room for ethical consideration, for it forces both community and developer to constantly reflect on their own values and the validity of them, it does not address certain problematic aspects.

Cultural Relativism. First of all, when should a developer set his own values aside and acknowledge somewhat opposing values of the community to avoid being paternalistic? In the interviews we have seen how strongly people can hold on to their own opinions, by saying others need to be educated. It could be true that in some instances education is the source of the value clash, but how could you know you are not imposing your own ideas? One could argue that the values of a community should prevail over the values of the developer, since the system is being build to support the local community. On the other hand, a developer has a responsibility in the process herself to add value to peoples lives without doing harm, and should therefore take her own doubts seriously. The role of a developer could be compared to the role of a doctor. A doctor has the potential to do enormous harm to a patient by choosing wrong therapy or overlooking a certain diagnosis. A doctor, therefore, does not blindly follow the wishes of the patient nor does she impose certain treatment on the patient without her agreement.The same responsibility should be felt by the developer. Although the doctor is still seen as a paternalistic figure, the current movement in medicine focuses on a more deliberative approach, in which patient and doctor have a voice.

Responsibility. This issue of responsibility can be even more complicated. In aiming to build sustainable systems, one should ask oneself how far the responsibility of the developer goes. Long-term consequences of a system are difficult, if not impossible to predict in the current landscape of fast progressing technology. Could the developer be held accountable for such consequences? This may change the willingness of developers to contribute to similar projects, and may hamper the progress of technology in low-resource environments. In medicine, accountability is captured in a strict legal framework so medical professionals know what to expect. Such a framework is not in place for developers working in ICT4D projects, resulting in a vague situation.

However, The responsibility, never solely lies with the developer. In ICT4D projects, co-creation is being used to develop a system which is tailored to the local situation. Co-creation entails that both the community and the developers work on creating a successful system. Therefore, both parties should be responsible for consequences. How this accountability works and whether this could free developers from their feeling of responsibility, is still an unanswered question, but something that should be taken into account when developing in low resource environments.

7.4 Lessons Learned

In this section we describe the lessons learned from ethical reflection of the Mali Seed Project, which can be used in other ICT4D projects. Firstly, co-creation can be a tool to facilitate culturally sensitive ethical reflection during the design of ICT4D solutions. It does not, however, facilitate reflection on all levels of an ICT4D project. It fails to address consequences of the envisioned system on a larger scale. Consequences for parties not directly involved, for example. Therefore we propose a new DM which involves ethical reflection in all layers of an ICT4D project.

7.4.1 Co-Creation as a Tool for Ethical Reflection

During the interviews we have seen the necessity for cultural sensitivity when it comes to ethical consideration. All parties involved may have the aim to do good, but what constitutes as ‘good’ and how you achieve it, may differ. The cultural background can shape the understanding of right action, for example. A way to be sensitive to cultural differences in ICT4D projects, is making use of co-creation []. In this way, voices of all stakeholders can be heard equally.

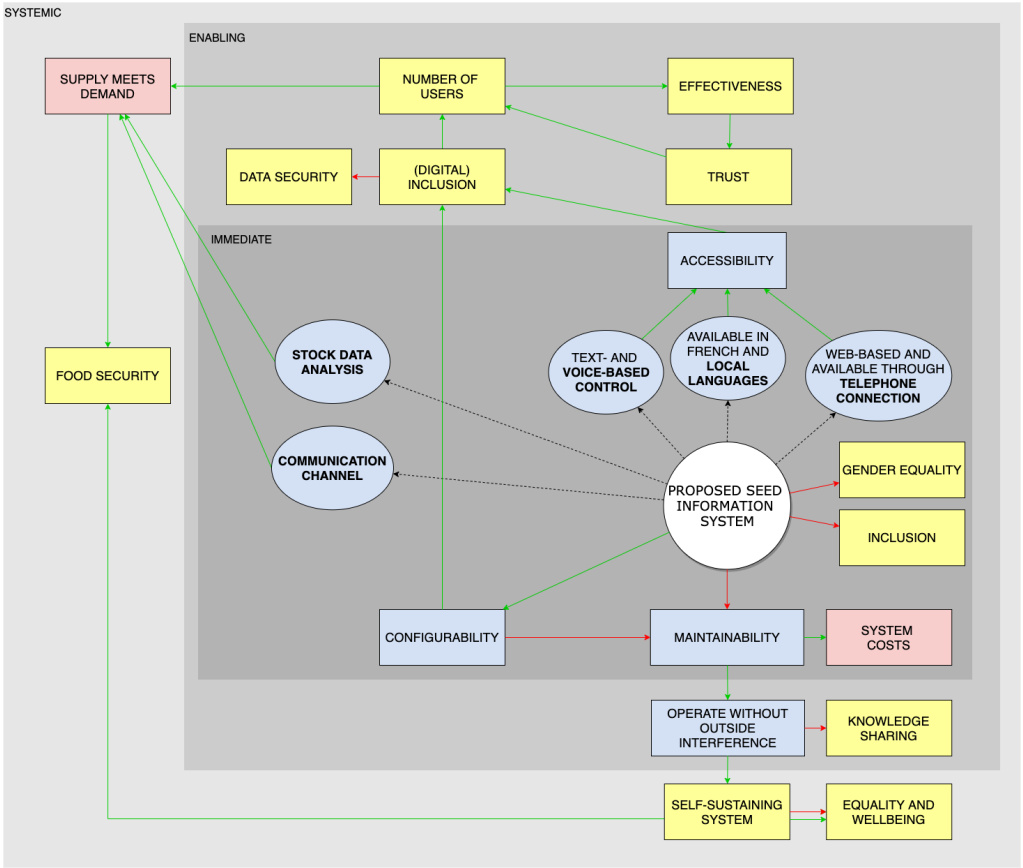

Figure 13 DM including ethical reflection as an overarching requirement in the current SIS.

Co-creation is, however, not the solution to all issues surrounding ethics in ICT4D. Power relations are difficult to tackle, and therefore achieving full equality, is challenging. A participatory approach also fails to give concrete guidelines on how to address value clashes during the project. Lastly, it does not address the problem of possible unethical consequences for parties that are not involved in the project.

7.4.2 Incorporate Ethics into the Decision Map

To incorporate ethics in ICT4D projects, it is insufficient to solely focus on the role of the researcher or developer. Ethics should be incorporated at all levels, and should even provide reflection at the systemic level, as inequality and *e.g.,* issues related to poverty, wealth, interests and power could exist at this level, with negative impacts for the envisaged beneficiaries. An example is the e-choupal ICT4D project in India [52]. This project started with the noble goal to help small framers with their trade, but resulted in providing profits solely to big companies.

To prevent such unintended result, we propose a Decision Map which visualizes that ethical reflection should be the overarching requirement of the entire project.

Although DM's with three levels are sufficient in most project environments, in ICT4D low-resource environments, notions mentioned in DM, get a new meaning. In environments with sufficient resources, for example, a situation where supply simply meets demand, is an adequate goal for a system. In these environments an adequate legal frame work and safety net is in place to prevent any harmful practices. In low-resource environments, such frameworks are often not available, which makes a goal to have supply meet demand insufficient. One should keep in mind possible negative consequences the system can impose on a vulnerable environment. For example, this notion does not contain which seeds are used. Is it about importing seeds or about empowering local farmers to meet demand? Furthermore, it does not address whose interests are served, the small farmers or big Agrodealers for example. This shows that it is possible to make a project sustainable without being concerned with ethical implications, which in high-resource environments would be prevented by legal framework and a safety net. Therefore, we

propose ethical consideration in the DM by providing examples of possible notions which could be negatively impacted by the SIS, in the DM .

In the DM proposed in Figure 13, these notions stress the need for ethical reflection to prevent the indicated negative impact. In the proposed DM of the Mali Seed Project, we included some possible negative impacts on each level which should induce ethical reflection. Firstly, digital inclusion can have a negative influence on data security, for it could result in misuse of data. We have seen in previous research by Taylor [42] that mobile data of individuals in low-resource environments can be used for tracking mobility which is a serious breach of privacy. Furthermore, we included negative side effects of a self sustaining system. Such a system can cause harmful practices to disrupt local context without a possibility to eliminate it from the system. Focus on the sustainability of a project should therefore always be accompanied by ethical consideration concerning the entire project. Lastly, we included the notion of gender equality and inclusion. These are not specific consequences of one of the aspects in the DM, but could be impacted negatively if the system fails to adequately address both men and women and include minorities or marginalized groups.

Overall, these recommendations for a DM are merely examples of areas where ethical reflection is needed. In practise, ethical reflection should be an overarching layer, surrounding every aspect of the DM . Then consideration of ethics can be facilitated in each dimension of ICT4D, to make a project worthy of sustaining.

8 DISCUSSION

In this interdisciplinary study, we aimed to answer the central research question: "*How can we define a general good practice for designing ethical and sustainable (software-intensive) systems in low-resource environments?*". We approached answering this question by conducting a case-study around the SIS to support the seed value chain in Mali.

From this case study, we learned that in order to introduce an information system that sustains over time, you have to look further than the system-specific design but consider the overall design space. In this design space, there are not solely technical considerations to make but many social, economic, and environmental considerations as well. When the system owner understands the impact within each of these sustainability dimensions, and the inter-dependencies between the dimensions, they can reason about the system evolution over time together with the long-term effects of the system on its environment.

It is an important notion that sustainability can only be measured over time. It requires time to understand whether a system or (digital) solution contributes to a long-term goal (such as food security). DMs and other modeling tools aid in reasoning about the expected effects, however, the actual future remains unknown. For instance, the SIS initially did not contribute to connect the traders and customers of seeds. However, in a recent interview with one of the developers of the voice-interface to extend the SIS, we learned that the trust in the system started growing. Hence, the success of a system should also not be concluded too soon after the system is introduced. Especially if this system is introduced in an environment that radically needs to adapt to the system as the current (societal) structures are not (yet) compatible with the system.

This also introduces a dilemma, if (external) development aid organizations or researchers contribute in introducing digital systems in low-resource environments, to what extent should the system adapt to its environment or the society to the system? There is not a general answer to this question, rather it should be asked within the specific context and answered by the local stakeholders that benefit from the system.

Ethics are dependent on the culture, hence, in introducing a software system the local ethical context needs to be investigated to ensure that local communities are not harmed. Embedding ethics in the design process is a vague notion. No literature is available on how to do this in an ICT4D context. The co-creational approach has an inherent potential to include ethical consideration, but still leaves room for some possibly problematic issues. The notion of responsibility should be discussed, just like to what degree you should be culturally sensitive as a developer.

Developing software in low-resource environments requires a different approach. In this context, there is often no access to the internet and smart devices. Moreover, the digital environment is often not tailored to the local context. This can be due to insufficient attention for the low literacy rate, little experience with digital devices, or language barriers. Therefore, developing software in a low-resource environment requires a different approach. In this approach, it is key to involve the stakeholders in the design process. This can be done with iterative design cycles in which a small prototype is realized, tested, and discussed with the local stakeholders.

Often development aid projects fail once the funding stops. Accordingly, it is of crucial importance to understand the strategy for the system to sustain over time. For this, you need to consider the economic, social, environmental, and technical sustainability

dimensions. Furthermore, when systems are designed from an outside perspective you risk imposing beliefs on a community that is not tailored to local values. Hence, ethical considerations should also be included in the design process.

Aiming to increase the sustainability of a project in a developmental setting is impossible without taking ethics into account. Once a project is sustainable, and hence is likely to operate on its own over an extended period of time, it should not have the potential to harm individuals or a community. On the other hand, starting a co-creational project in a community that adds values to people's lives and refrains from harming should be made sustainable. If such a project fails, not only the time and efforts of the community have gone to waste, the community is also deprived of valuable opportunities that could help them in their daily lives. As sustainability and ethics are intertwined, they could not be analyzed and promoted on their own. We, therefore, proposed changes to the DM to include ethical reflection.q

Although we worked closely together with the local stakeholders, we have to be critical of the fact that the analysis was mainly conducted from a Western perspective. We emphasize the need for deliberation, but due to challenges in communication, the analysis can only in part be labeled as co-creational in collaboration with the user community. We did interview some stakeholders, but the majority of data we analyzed, was extracted from previous studies (namely [30, 7]).

Another limitation of the introduced methods is that the modeling techniques help to reason about future effects but cannot actually predict the future. Using modeling techniques to understand the effects and inter-dependencies of sustainability and ethical concerns in the design space is useful to reason about the effects a system might have on its environment. However, it is crucial to understand that these effects and inter-dependencies are predictions that are not guaranteed to hold. After the design process, the effects of the system should continuously be monitored to understand the actual effects. If these are different than expected, the system and design space should be updated accordingly.

We used an exploratory approach to shed light on how ethics could be incorporated in the design phase of an ICT4D project for little literature is available on this topic. We interviewed experts in an exploratory dialogue to understand their views on this issue. Although this approach could give an idea of how ethics could be incorporated, more analysis is needed to understand how ethical consideration in an ICT4D project takes place as of now. With this knowledge, blind spots can be recognized and adequate recommendations can be proposed to give ethics a more prominent position in the iterative design process of an ICT4D project.

Looking back at and analyzing the design phase of the SIS, it is more straightforward to look at ethical consideration that has taken place, than to shed light on those instances where ethical consideration should have taken place but did not. Therefore, the co-creational approach could give a too optimistic view of the potential for ethical consideration. In the future, this analysis should take place during the design process, instead of after.

9 CONCLUSIONS AND FUTURE WORK

In this study, we conducted an interdisciplinary research to define a general method to include sustainability and ethics into the software design in the development of digital platforms in low-resource environments. To achieve this, we conducted a case-study around the SIS in the seed value chain in Mali. This study served three objectives.

First of all, we aimed to contribute to the ICT4D research community by providing a methodology to improve the software development process in low-resource environments. Our main contribution is a description of a design process in which sustainability and ethical concerns are included early on in the design space. This is important to ensure that digital platforms sustain over time and can be operated by local resources without imposing negative effects on the local community. Co-creational design creates space for ethical consideration to prevent such consequences while being culturally sensitive. More reflection, however, is needed to give ethics a prominent role in the design process of an ICT4D project.

Second, we aim to contribute to the software engineering process of the SIS. The SIS is introduced to connect traders and buyers of seeds meant for food production. Accordingly, the SIS aims to contribute towards food security. Initially, the SIS excluded important stakeholders such as farmers. To include the farmers, the SIS is currently extended with voice-interface. This allows access for stakeholders who have no access to internet and are not able to read and write. In our study, we aim to influence the design of the SIS so that the SIS becomes context-sensitive and does not harm the local communities. We achieve this by including sustainability and ethics in the design space.

The last objective of this study is to aid the local stakeholder community. We contributed by providing models and documentation of the current SIS and its environment. Moreover, we proposed concrete changes to the SIS to contribute to a context-sensitive system.

The research around the Malian seed value case is ongoing. Currently, researchers and developers are implementing the voice services, conducting the user tests, and continuing the iterative process of requirements elicitation. The researchers aim to scale up the digitized seed value chain and aim to study its (decentralized) governance structure to ensure eco-system sustainability. Moreover, a data analysis tools for monitoring and evaluation of the emerging digital seed trade will be set up. Meanwhile, the research is conducted regarding AI-based tools to improved voice interaction in local African languages (ASR and Text-to-Speech), and methodologies to process under-resourced languages. This is all part of an interdisciplinary/transdisciplinary approach to tackle global challenges related to the digital society in low-resource environments.

Finally, we discuss some of the research gaps that remain unanswered by our study. Although it has become evident that the dialogical aspects of co-creational design leave room for ethical consideration in ICT4D projects, whether this suffices, remains unknown. This approach does not address possible negative consequences that do not directly harm the community but have an effect on groups or individuals outside the community. Implementing ICT solutions in low-resource environments could have a disadvantageous effect on others who are not included in the design process.

Another question is where the responsibility lies. In a co-creational approach, both community and developer work on building a system that is beneficial for the community. If such a system would have negative consequences, who should be held accountable?

The degree to which a developer should be culturally sensitive is difficult to determine and depends on the situation. By providing more examples of instances developers were and were not culturally sensitive should be shared. In this way, a developer can be more susceptible to recognize instances where reflection is needed on the adequate degree of cultural sensitivity.

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Appendix

A Definitions

Table A1 Definitions of the Features/Requirements from the Decision Map of the Current Seed Information System.

Available in French	The information within the system is available in French.
Text-Based Control	The main form of communication in the system is textual.
Web-Based	The system is accessible through the World Wide Web.

Table A2 Definitions of the Sustainability Quality Concerns from the Decision Map of the Current and Proposed Seed Information System.

Accessibility	The system can be used by people with the widest range of characteristics and capabilities [26].
Configurability	The ability to modify and extend a system while it is running [47].
(Digital) Inclusion	Digital inclusion refers to strategies that provide training, services, or opportunities designed to address the challenges of the digitally disadvantaged [46].
Food Security	Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life [53].
Operate without Outside Interference	The system does not require external aid to operate.
Maintainability	(Modifiability:) The system can be effectively and efficiently modified without introducing defects or degrading existing product quality [26].
Number of Users	The number of users that actively uses the system.
Effectiveness	Accuracy and completeness with which users achieve specified goals [26]. In this context: the seed stock data in the SIS is similar to the actual seed stock.
Trust	The stakeholders have confidence that a product or system will behave as intended [26].
Self-Sustaining System	The local community is capable of operating and maintaining the system with local resources and knowledge.
Supply Meets Demand	The seed stock is sufficient to meet the demand for seeds.

Table A3 Definitions of the Features/Requirements from the Decision Map of the Proposed Seed Information System.

Stock Data Analysis	The seed stock data and transactions can be analyzed for the purpose of providing an overview of the current availability of seeds and predicting the future demand.
Communication Channel	The system allows communication between the relevant stakeholders.
Available in French and Local Languages	The information within the system is available in the French language and other local languages such as Bambara.
Text-Based and Voice-Based Control	The communication in the system can be both textual and voice-based.
Web-Based and Available through Telephone Connection	The system is accessible through the World Wide Web and through a telephone connection.

B Interview Protocol

All interviews were conducted online, using Zoom.us. Four themes where discussed. For each theme, multiple questions and follow-up questions were asked to further reflect on the respective theme.

We started the interview with a short background in which we explained how the Mali Seed project started and what it entailed. Then, the issue of incorporating ethics in such a project was shared, with the concern how cultural sensitivity can be involved.

B.0.1 Theme 1: Cultural background and context of interviewee

How did you become interested in the field you are working in? Follow-up questions: where are you from?

B.0.2 Theme 2: Foreseen challenges of fast developments in the field of technology

How could technology, in your opinion, prove to be harmful in the future? Follow-up questions: In the context of AI, many envision that it could take over the world and be harmful. What are your views on this? When should we be careful using technology?

B.0.3 Theme 3: Embedding ethics in context of the interviewee

We are concerned with how we can incorporate ethical consideration in the design process of computer information systems. Is that something you are concerned with? Follow-up questions: In what way? Do you see others in you field involving ethical consideration in their developmental work or ICT development?

B.0.4 Theme 4: How to address value clashes due to cultural differences?

Follow-up questions: In our project we are conscious that various people with various cultural backgrounds work together. These various backgrounds can result in different beliefs and values, which could clash during the design of ICT solutions. How do you view developers should address such a value clash? Example: In certain projects, the notion of gender equality is a debated topic, often caused by cultural differences between developer and community, how should developers address this clash?

Acronyms

AI Artificial Intelligence. 2, 5

AOPP Association des Organisations Professionnelles Paysanned. 4, 9, 13, 15–17, 19, 21, 24, 27

ASI Amsterdam Sustainability Institute. 2, 6

DM Decision Map. 3, 7, 8, 14–17, 19, 21, 23–25, 35, 37

DMs Decision Maps. 3, 5, 7, 29, 36

DNA National Agriculture Division. 11

ICT4D ICT for Development. 5

ICT4FoodSec ICT for Food Security. 6

IER Institute of Rural Economics. 4, 12

QOC Questions Options Criteria. 25

SIS Seed Information System. 2–5, 7–9, 13–28, 35–37

SQ Sustainability Quality. 3, 5, 7, 8, 15, 16, 24

SQs Sustainability Qualities. 7, 16, 17

SSN National Seed Service. 12

UML Unified Modeling Language. 7, 14

W4RA Web alliance for Regreening in Africa. 5