Tibaŋsim: Information Access for Low-Resource Environments

Francis Dittoh (https://orcid.org/0000-0002-4300-5835)[1,2], Hans Akkermans[2]
Victor de Boer, Anna Bon, Wendelien Tuyp, and André Baart[3]

[1] University for Development Studies, Tamale, Ghana
fdittoh@uds.edu.gh
[2] Vrije Universiteit Amsterdam,
Amsterdam, The Netherlands
Hans.Akkermans@xs4all.nl, v.de.boer@vu.nl, a.bon@vu.nl, w.tuijp@vu.nl
[3] Bolesian BV,
Utrecht, The Netherlands
andre@andrebaart.nl

Abstract. In Africa, and other places around the world, there are numerous people who do not have access to information from the World Wide Web or other digital sources. This is not an issue of infrastructure only, but also of cultural and social factors, including low literacy. Most rural communities in the Northern Region of Ghana fall in this category, where information in written form and/or English is not accessible due to the inability of majority of community members to read and write. This paper presents Tibaŋsim (originally "RadioNet"); a case-study of an appropriate ICT4D methodology in the development of an information delivery system hosted in low-resource areas, with empirical data from context analysis from the rural communities and other stakeholders. The paper also presents, an evaluation of the system and the methodology, by way of User Evaluation and System Monitoring. The paper also shows how contextual issues are catered for through the methodology used. Tibaŋsim focuses on available technologies and appropriate information formats by providing a system that relies on GSM and FM Radio, in the local language(s) of the community. Tibaŋsim was deployed in 5 rural communities, reaching a total of almost 1000 people, providing them primarily farming-related information. . . .

Keywords: ict4d, low-resource, information access, unconnected, digital divide, voice technologies, mobile, radio, user-centered design, rural, Sub-Saharan Africa

1 Introduction

The digital divide, which is the uneven distribution in the access to, use of, or impact of Information and Communication Technologies between any number of distinct groups, is a problem that has plagued the world since the inception of the World Wide Web. As of January 2020, about 4.54 billion people are using the internet, which is about 59% of the world's population [1]. Admittedly, this is a step up from the previous years, however, certain regions retain very high numbers of unconnected and a majority of these have very little access to information of any kind. Only about 24.4% of Africans are connected to the internet [2]; meaning over 1 Billion Africans have no internet access. The reasons for this low level of access to the World Wide Web and subsequently, to relevant information are; Lack of Infrastructure, Low Incomes and Affordability, User Capabilities; basic literacy and digital literacy, Lack of Incentives for Access; lack of awareness, relevant content, and cultural or social acceptance [3].

In this paper, we show a case study that tackles the above issues respectively by; relying on existing systems (Radio and GSM), utilizing low-cost hardware and assessing financial sustainability, focusing on voice-technologies (mobile and radio), and utilizing a user-centered design methodology with early stakeholder involvement.

This paper presents Tibaŋsim (a Dagbanli[4] word that translates to "Our Knowledge"); a case-study of an appropriate ICT4D methodology (See Figure 1) in the development of an information delivery system hosted in low-resource areas with empirical data from context analysis from the rural communities and other stakeholders, which guided the design process and produced an information delivery system for rural communities. The paper further presents an evaluation of the system and the methodology, by way of User Evaluation; an analysis of Usability, Learnability, Availability, and System Monitoring; to evaluate the technical feasibility of the hardware deployed in rural areas. The paper also shows how issues such as Infrastructure; Literacy; Content Relevance and Quality; Cost-effectiveness and Affordability are catered for through the iterative and user-centered methodology used .

1.1 Lack of Infrastructure

In Ghana, where this project was carried out, voice-telephony, television and radio are existing systems that function adequately, where radio and voice-telephony are more utilized in the rural areas. However, there is an internal urban-rural divide, which means even further deterioration of services in the rural areas [4]. This is clearly seen in the areas of electricity and internet connectivity which are less available and reliable in rural communities as opposed to urban communities [5].

1.2 Affordability

In Ghana, voice and internet services have national-wide coverage [6], but the cost of hardware and the cost of subscription required to access some of these services (e.g. internet, voice calls) remain unaffordable to many in both rural and urban areas. As such these technically feasible services remain financially unfeasible [5].

4 https://en.wikipedia.org/wiki/Dagbani_language

1.3 Literacy

In the unlikely event that all required infrastructure was available, and hardware and services were affordable by everyone, the issue of literacy remains a barrier to the delivery of information in the current World Wide Web formats. Ghana has a literacy rate of 76.67% and a youth literacy rate of 90.6%. However, the rural north, which happens to be a major food source for the country, retains the lowest literacy rates [7]. Currently 80 percent of online content is available in only 10 languages, which only around 3 billion people speak as their first language [8]. In addition, information available online is heavily biased towards text and thereby discriminates (perhaps unintentionally) against those who cannot read and write [5].

1.4 Relevant Content

One major barrier to connecting the unconnected has been that they do not find the information, even if available, to be locally relevant enough to warrant the effort to gain access to it [3]. The availability of information relevant to the livelihood of the end-user is a viable incentive to get connected.

1.5 Available Technologies

In the attempt to circumvent the issues of lack of infrastructure and unaffordability, it is important to center innovation on 'technology-in-use' as opposed to 'technology-as-invention' [9]. The extreme increase of mobile telephony in rural Africa [10] has led to the emergence of ICT4D projects, research and solutions that aim to utilize these existing technologies, namely, SMS [11][12], Mobile Web [13], Voice Technologies [14] and Radio [14][15] to aid various aspects of development. Some of these have failed completely [12] due to their reliance on technologies that are circumvented by low literacy (namely SMS) and for the same reasons, some have not been able to scale up effectively in the rural areas [11] since, based on empirical evidence, SMS is hardly used by folk in rural areas in Ghana [7]. It is therefore important to utilize available technologies in ICT4D innovations but also to ensure that they are used with contextual issues (e.g. literacy) in mind.

This project tackles these challenges by building a system that has as little reliance to large infrastructure as much as possible (See Section 3.3.4), is cost-effective in terms of setup costs and user costs (See Section 3.4), is focused on local languages and voice technologies (See Section 3.3.4), and relies on technologies available within the communities (See Section 3.3.1)

2 Related Work

2.1 Making Waves

In 2016, in war-torn Democratic Republic of Congo (DRC) in the town of Uvira, War Child implemented a radio-based education program that provides young girls who are currently not enrolled in school with the opportunity to continue their education. War Child setup 10 locations where radio-based education programmes are broadcasted from a radio station [5].

"Making Waves" further assessed if using radio-based accelerated learning programs to reach out of school secondary students is an effective way to bridge the education gap faced by many children in the DRC. The initial results from the program were positive: instructors were trained, classes were up and running, and the majority of students passed their first exam – for many it was the first exam they had taken in several years.

The initial pilot project concluded in 2017 and the results were very impressive, with pass rates as high as 95 percent. Now, War Child is working with the Congolese Ministry of Education to take the program nationwide and ensure that girls throughout the country will finally have access to a safe education and a chance at a successful future [6].

Tibaŋsim has the potential of decentralizing projects like Making Waves, enabling multiple custom lessons (audio fragments), accessible at any point in time and not having to rely on a single broadcast.

2.2 Esoko

Esoko is an agricultural profiling and messaging service managed on the web and delivered via mobile. The Esoko platform provides automatic and personalized price alerts, buy and sell offers, bulk SMS messaging, stock counts and SMS polling [11]. In 2016, ESOKO partnered with Vodafone to offer farming advice, weather updates and market prices with a dedicated Farmers' Club SIM. Vodafone was keen to use the service as an opportunity to increase rural penetration through new acquisitions, although the service was eventually offered to existing rural subscribers in December 2016. The service is available in 10 languages.

Due to its reliance on a particular network, there is a limitation of its reach (Vodafone has only 21% of the Ghanaian mobile subscriber base [7]). Language is still also an issue, since 10 languages is, at best, about 12% of the languages spoken by illiterates in Ghana (there are over 90 main indigenous languages in Ghana [8])

Tibaŋsim seeks to increase reach, since it's not dependent on any particular network and/or radio station. It also provides good scaling in terms of language, since every deployment can be language specific.

[5] https://warchild.ca/congo/making-waves-radio-based-learning-brings-education-young-girls-drc/
[6] https://warchild.ca/congo/backtoschooldrc2019/
[7] https://www.nca.org.gh/assets/Uploads/Quaterly-statistics-03-11-16-fin.pdf
[8] https://www.justlanded.com/english/Ghana/Ghana-Guide/Language/Languages-in-Ghana

2.3 Radio Marché

Radio Marché [14] is a voice-platform that enables farmers broadcast their offerings of produces like sheabutter and honey on the local radio using innovative voice technologies. The service marks the first phase of the pilot of the VOICES Project [16]. RadioMarché, which was built to improve communication between the farmers and their potential customers, was designed according to the requirements as defined by the Malian W4RA partner Sahel Eco, in close collaboration with 19 villages in the Tominian region in Mali. The VOICES Project also highlighted the ineffective nature of solutions based on SMS within the context of rural Africa, the need for low-cost solutions, easy-maintenance and robust system. Tibaŋsim draws from these lessons to develop a system that meet these necessary requirement but goes further to automate the broadcast process and downscale (disintegrate and localize) the information delivery system to the community level.

2.4 Kasadaka

The Kasadaka [17] platform was developed to support easy creation of local-content and voice-based information services, targeting currently 'unconnected' populations, taking into account contextual and infrastructural requirements, and matching local ecosystems. The Kasadaka platform and its Voice Service Development Kit support the development of decentralized voice-based information services, to serve local populations and communities in their own local languages, in regions where Internet and Web are absent and will continue to be for the foreseeable future. Tibaŋsim is developed, partially on the Kasadaka Software Development Kit.

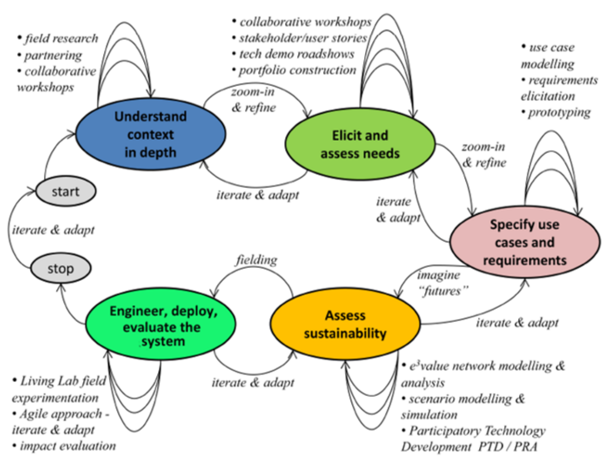

Fig. 1. ICT4D Methodology [5]

3 Methodology

This study used a collaborative, adaptive and iterative methodology (see Figure 1) to identify and tackle the issues from a socio-technical standpoint [5]. The study also forms a validation of the methodology by providing a practical application to an information system design and implementation.

3.1 Research Area

The research focused on East Gonja District of the newly formed Savannah Region of Ghana. The Savannah Region covers about 15% (35,862Km2) of the nation's surface area. It has a total population of about 2 Million and by contrast has a far lower literacy rate compared to the national rate. This area is selected for our case studies because its rural areas fit the targeted group; being an agriculture-production region, having impact on the nation's food security and therefore in dire need of up-to-date information, but being more deprived of infrastructure, and with higher illiteracy rates. Five (5) communities were selected from the East Gonja District of the Savannah Region of Ghana, namely Kpandu, Dabogshei, Wulanyili, Dalogyili and Daashei. These are typically small communities with about 20 to 30 households with roughly 200 to 250 people per community.

Fig. 2. Savannah Region of Ghana

3.2 Context Analysis and Needs Assessment

The project is a vital part of a wider research on innovative information systems for developing countries using an interdisciplinary approach for context analysis and needs assessment. This phase is important because different stakeholders (users, developers) and as such it is essential to bridge cultural distances at the

Table 1. Operational Goals of Stakeholders

Stakeholders	Operational Goals
CSIR-SARI	Utilization of the service to reach the numerous communities served by the organization. SARI's mandate is to provide farmers in the Northern Sector of Ghana with appropriate technologies to increase their production based on a sustainable production system. Information dissemination is a vital component in this.
Agricultural Extension Agents	Utilization of the service to replace the manual (and tedious) dissemination of information to numerous communities and organizing meeting schedules remotely.
Crop and Animal Farmers	Receiving general agricultural related information, advise on planting times, information on crop and animal diseases, seeds, fertilizer, market prices and weather information
Producers	Receiving information on production methods (mainly shea butter), market prices of produce and possible sales outlets
Local Developers	Running the system on commercial basis; scaling up; making profit
Rural Host	Hosting hardware and possibly generating some income from the service

earliest stage. This is done by teaming up, creating partnerships and expressing interest in each other's ideas and expertise[5].

In 2015, a collaborative workshop, ICT for Food and Water in Ghana - Collaborative Research by VUA and UDS, was organized in Walewale, Ghana by Vrije Universiteit's Web Alliance for Regreening Africa (W4RA) team, together with a team of researchers from the University for Development Studies, Tamale, Ghana.

The team consisted of a multi-disciplinary group of experts in rural economics, animal science, tropical agronomy, irrigation, microfinance, sustainable land management, gender, value chain development and ICT4D. The workshop brainstormed around the various technological possibilities for information delivery systems related to food and water security. Experts weighed in from all angles on issues like technological feasibility, financial sustainability, gender inclusion and especially the local context.

In 2018, interviews with experts from The Savanna Agricultural Research Institute (SARI), located in Tamale, Ghana, which is working directly with local farmers in the region, provided further insight in the areas of agriculture; communication; language and information dissemination in the local context. SARI further facilitated communication with rural farmers to get insight into their specific needs and ideas on what is useful for them.

The evaluation of the issues pertaining to the digital divide, workshops with multi-disciplinary groups and interviews with stakeholders enabled us to *understand the context in depth* (See Figure 1). Coupled with the understanding of the operational needs for the various stakeholders (See Table 1), led to aid *elicit and assess the needs*(See Figure 1) of the proposed system.

3.3 Use-Case and Requirement Analysis

Through an iterative process, stakeholders and end-users provided insight into the needs of the system. In assessing the local infrastructure, by field visits and interviews with SARI and other organizations, the unavailability and/or unreliability of certain information communication technologies that could have been in consideration was confirmed. The rural areas of the Salaga District was found to have unreliable internet at best and in most communities often slow or unavailable. In contrast, GSM and radio reception was found to be available and often reliable.

Pre-Analysis and Findings Interviews were carried out with 106 community members in five (5) communities, in a total of 2 sessions each; a structured interview, to obtain empirical data on the rural context (prior to development) and a System Usability Scale survey (after deployment), to measure the usability of the system from the end-user point of view.

We present the most important findings from the structured interview.

Demographics There were a total of 61 males (57.5%) and 45 females (42.5%) of which 97.2% are married. This gives an indication of some appreciable balance in the gender ratio for this project, which in turn is helpful to ensure equality.

84% of survey participants had no education, with only 5.6% having reached beyond elementary school. In addition, only 1.6% speak English. This indicates the low levels of literacy and thus the need for the system to be in local languages understood by members of the community and also not based on text.

In terms of occupation, 82.3% were found to be farmers (crop and/or animal), 5.3% traders, 5.3% producers (mainly shea butter) and 6.2% artisans. This is important especially after deployment, giving information providers an idea of the people they are serving.

Technologies Out of 106 end-users interviewed, 74 owned mobile phones (69.8%) or had access to a mobile phone (99%) (Ghana has a mobile penetration of 139.8% [18]). With regards to radio, end-users owned radio sets or had FM radio on their mobile phones (71.7%) or had access to a radio set (97.2%). Using the analysis of a Likert scale [19], which assigns numerical values to ordinal data by giving each a value (Not at all, Seldom, Normally, Regularly and Very often) on a scale (the most common scale is 1 to 5), the mean of frequency of end-users listening to radio was 3.58, with a median of 4 (Very often). Other research has found very little to no use of SMS and little to no use of smartphones in the rural areas of northern Ghana [7] and this is further confirmed in this research where the analysis of a Likert Scale on the usage of SMS (sending SMS) shows a mean of 1.44 and a median of 1 (Not at all). This has been found to be due to the inability to read and write.

Information Needs Community members were asked what type of information they would like to receive on a regular basis. From a multiple response analysis, Farming is the highest mentioned by 98.1% of respondents, followed by Market Prices (mentioned by 43.8% of respondents), Seeds (mentioned by 37.1% of respondents) and Weather (mentioned by 35.2% of respondents). Other information types of note are; Health (25.7%), Adverts for sale of produce (22.9%), Plant disease, animal farming and animal disease (mentioned by 19.0%, 18.1% and 16.2% of respondents respectively).

This gives information providers a good indication of the prominent types of information that would have to be obtained and translated for the service.

This analysis guided the project to *specify the use case and requirements*(See Figure 1)

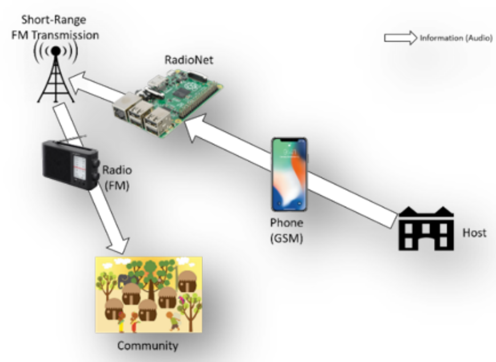

Fig. 3. Sketch of Tibaŋsim

Key Idea To create an information access system for local communities by providing an FM broadcast system. This will enable rural communities to get access to relevant voice-based information in their own language(s). This will involve the design of a low-cost system, built on the Raspberry Pi with Solar Power-Banks that stores recorded voice fragments over GSM calls and broadcasts it over FM on short-range (see Figure 3).

Actors and Goals The following table outlines the various actors within this project and their intended goals

Table 2. Actors and Goals

ID	Actor	Description
1	User	Tune to FM Frequency on Radio Set to get information
2	Community Leader(s)	Host Hardware in appropriate location
3	NGO/Institution	Obtain, translate and call into system to record relevant/requested information
4	Support	Monitoring/Maintenance

Key Requirements Following an understanding of the context and the needs analysis, as well as considering the technologies available, the following are the key requirements of the system;

Non-Functional Requirements

- Maintainability - NGOs/Companies and Institutions should have the ability to maintain the system and update information with ease
- Availability - Users should have the ability to reach the system at all times. As such, barring mobile network issues, the system should be hosted on a platform that will be available at all times
- Scalability - The system must have the ability to scale to different locations and for any number of subscribers and the system should be easily replicable
- Reliability - The system must ensure that information is as accurate as possible
- Usability - The targeted user group creates a requirement of simplicity in the user interface
- Cost-Effectiveness - The whole system must work together to be financially sustainable

Functional Requirements The functional requirements are shown in a MoSCow format as follows;

Table 3. MoSCoW

Must Have	Interactive Voice Response
	Local Language(s)
	Regular Information Updates
	Short-Range Radio (FM) Transmission of information
	Monitoring
Should Have	Uninterrupted power supply
Could Have	Community-level Subscription-based service
	Wide-Range Radio (FM) Transmission of information

3.4 Feasibility and Sustainability Assessment

It is important that the system outlasts the initial project so as to be truly beneficial to the communities. As such, we *assess the sustainability* (See Figure 1) by considering the technical and business/socio-economic feasibility as well as possible goal conflicts, dependencies and preconditions required for the system to function as a whole [5].

The project also focused on the system being fit for the rural context. As such, technically, the design is as simplistic as possible, focusing on affordable hardware, open-source software and not requiring additional hardware and/or skills from the end-users.

Discussions with stakeholders showed that information delivery to and from rural areas is often an issue and as such a system that aids this is economically viable provides them with a way of not only saving time, but also delivering information they would have before now not been able to.

A further analysis of costs pertaining to financial sustainability of the system are as follows;

Hardware Costs Tibaŋsim was built on low-cost hardware. The system runs on a Raspberry Pi 3B+ and requires an SD-Card, a Huawei 3G Modem and a GSM Sim Card. A power bank was also added to the package. At the approximate costs of $40 for a Raspberry Pi 3B+, $40 for a powerbank, $17 for a 3G Modem and $7.50 for 32GB SDHC Card, the total hardware cost for a single deployment stands at $104.50.

Open-Source Software Tibaŋsim was developed on top of the Kasadaka Platform (See Section 2.2). The main software component that enables the development of voice services is called the Voice Service Development Kit (VSDK) which runs a stack of (mostly open-source) applications that provide the different functions that are required for voice-based interactions. Asterisk,an open-source telephony exchange application is used in conjunction with chan_dongle (an interface to phone modems) and VXI (a VoiceXML interpreter), to provide the voice-based interactions through the local GSM network[17].

The FM Broadcast Module of Tibaŋsim was developed using Pi-FM-RDS, which is an open-source module that generates an FM modulation, with RDS (Radio Data System) data generated in real time. It can include monophonic or stereophonic audio. It is based on the FM transmitter created by Oliver Mattos and Oskar Weigl[20]. It is compatible with both the Raspberry Pi 1 (the original one) and the Raspberry Pi 2, 3 and 4[21].

Finally, Bash-Over-SMS, the monitoring/updating module of Tibaŋsim, was developed using Gammu. Gammu is an open-source command line utility that provides access to wide range of phone features including SMS retrieval, backup and sending[22].

Setup Costs Tibaŋsim is built with rapid deployment in mind. As such, the process of setting up involves writing the Tibaŋsim Image to an SD Card (ETA; 2 to 5 minutes), obtaining a SIM Card with its corresponding phone number, connecting all these peripherals together and turning the system on. First boot may take up to 20 minute, making a maximum of about 30 minutes required for setup. As such, the setup process even during a scaled up deployment will incur little to no cost.

Running Costs Regardless of how effective cost reduction is, there are unavoidable costs (however small) that any information delivery system will incur during its operational phase. Tibaŋsim requires power supply and access to the local telephone network. The host, a selected community member, is responsible for this. The information providers are also required to make calls into the system to leave messages, and the monitoring system requires the use of SMS through the local telephone network. Through the use of low-cost hardware and technologies, the running cost is firstly distributed and also minimal. Based on discussions with stakeholders, we however propose a business model for the running of Tibaŋsim.

Proposed Business Model A subscription-based service is proposed, where the information providers (in this case, the Council for Scientific and Industrial Research - Savanna Agricultural Research Institute (CSIR-SARI)) are able to keep the system sustainable by funding information updates as well as monitoring and maintenance, from funds generated from subscriptions per community.

Some funds will also be made available for the hosting of the hardware (mainly cost of power and the hosting service). Note that the hardware is hosted within the community by a selected member. To further validate/formalize this model, we use the e^{3}value. Containing a small set of concepts and relations, this allows us to do easily apply it in out iterative step with changes which aids rapid development. The e^{3}value methodology represents networked business models in

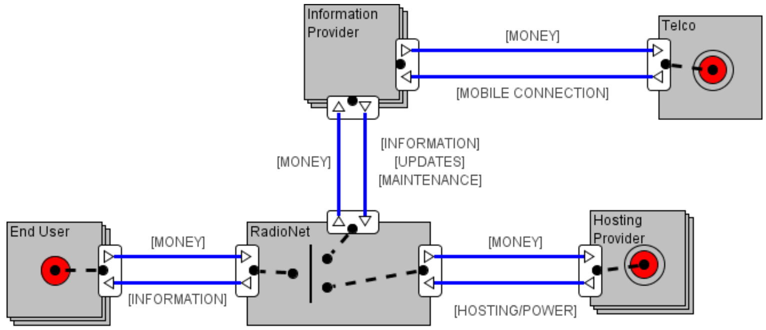

Fig. 4. Proposed Business Model - e^{3}value

terms of end users and enterprises, as well as the things of economic value they exchange with each other.

e^{3}value assigns economic value to the things exchanged, set pricing models, the number of customer needs, the actors involved and required investments. Actors are profit-loss responsible entities, such as organizations, customers and intermediaries. A Market segment is used to represent a group of similar actors (such as a pool of users), Value transfers are transfers of value objects, such as a payment or the delivery of a service, and Value objects are things of economic value which can be exchanged, such as money, services, products, knowledge or experiences[23].

The e^{3}value system proposed for Tibaŋsim (see Figure 4), has the Information Provider (e.g. CSIR-SARI) as an example of a market segment, exchanging information, maintenance and updates of the system for money (a value object) which in turn is used to pay for mobile services from the Telecommunications Provider (an actor). The information uploaded into the system by the Information Provider, using the services of the Telecommunications Provider is accessed by the end-user in exchange for a flat-rate community subscription which provides the funds needed for the Information Provider and for the Hosting Provider, who will provide services that ensure the uptime and upkeep of the hardware system.

Call rates for MTN Ghana[9] (the most widely used Telecommunications Provider) stands at GHC 0.1198/min ($0.022/min) for a local call (GHC - Ghana Cedis). A typical voice segment from the Information Provider (based on durations from the pilot phase) is about 5 mins. Using an estimation of one voice segment per day, call costs will be at GHC 0.599/day ($0.11/day) or GHC 17.97 per month ($3.41 per month). An addition of GHC 5 per call can be made as incentive to the personnel that will make these calls daily. This could help with the creation of controlled crowd-sourcing for translation and recording of the daily voice segments; this will result in a total of GHC 150 per Month ($28.50 per month). An estimate of GHC 50 per month ($9.50 per month) can also be made for the

[9] https://mtn.com.gh/insight/tariffs/

Hosting Provider. Maintenance and Monitoring of the system requires the use of SMS, which is estimated at 5 GHC per month (SMS Bundle of 1800 SMSes).

Table 4. Expenditure (Running costs)

Service	Cost/Month (GHC)	Cost/Month ($)
Call Tariffs	17.97	3.41
SMS Bundle	20.00	3.80
Call Service	150.00	28.50
Hardware Hosting	50.00	9.50
TOTAL	**237.97**	**45.21**

This will put total running cost of the system at about GHC 237.97 ($45.21) per month. The proposed subscription cost, based on discussions with stakeholders and end-users is GHC 10.00 ($1.90) per month. With a lower estimate of 50 farmers per community, that puts income at GHC 500.00 ($95.00). The profits made will then cater for monitoring and maintenance (See Table 4).

The above proposed financial model using the e^3value methodology provides a detailed model that can ensure the economic sustainability of the project.

4 Implementation

4.1 Development

Based on the Context Analysis and Needs Assessment (see Section 3.2), Use-Case and Requirement Analysis (see Section 3.3) and the Feasibility and Sustainability Assessment (see Section 3.4), the various components of the system were *engineered, deployed and evaluated* (see Figure 1) in multiple iterations with adaptations in a Agile approach coupled with an adapted living lab approach[5].

Hardware Tibaŋsim was built on the Raspberry Pi 3B+ [10], tiny credit card size computer that was designed in the UK by the Raspberry Pi Foundation. Originally intended to assist in teaching computer science, the Pi's accessible price makes it popular with hobbyists/makers/hackers who use it to create everything from Living Room PCs to Robotics Projects, and now, rural ICT4D Projects. The Raspberry Pi 3B+ runs a Quad Core 1.4GHz Broadcom BCM2837 64bit CPU, with 1GB RAM (2GB and 4GB RAM versions available) and requires a power supply of 2.5A. It also has a 40-pin extended GPIO, of which, vital to this project, GPIO Pin 4 transmits its FM signals. The Raspberry Pi 3B+ requires an SD-Card to run its Operating System.

[10] https://www.raspberrypi.org/

Tibaŋsim also required a Huawei 3G Modem that is chan_dongle capable [11] and a GSM Sim Card. A power bank was also added to the package to ensure uninterrupted power supply.

Voice Input: Kasadaka The Kasadaka platform was used for the system's audio input module.

Kasadaka enables the development and hosting of voice-based information services, targeted at low resource environments. The platform was run on the Raspberry Pi, which is a low-resource computer based on an ARM processor. The Raspberry Pi runs a Raspbian, a Debian-based Linux distribution. To provide the Raspberry Pi with connectivity to the local mobile phone network, USB 3G modems were used. The VSDK allows for the rapid development of voice service (prototypes) in a web-based development environment. The VSDK also generates VoiceXML files, which describe the possible interactions in a voice service.[17]

The Voice Input Module of Tibaŋsim is the user interface for the Information Provider. On calling into the system through the use of any mobile phone, from anywhere with GSM coverage, the Information Provider encounters a pre-recorded voice prompt welcoming them to Tibaŋsim and immediately allowing them to record a message. After recording the system will then play back the message and ask for a confirmation or a do-over.

At the backend, on confirmation, the audio fragment is stored in Kasadaka's file storage

Broadcast System: Pi-FM-RDS The Tibaŋsim FM Broadcast System was built using Pi-FM-RDS.

Pi-FM-RDS generates an FM modulation, with RDS (Radio Data System) data generated in real time. It can include monophonic or stereophonic audio. The transmitter uses the Raspberry Pi's PWM generator to produce VHF signals.[21]

Pi-FM-RDS generates its audio from an audio stream or file. It will automatically filter and sample audio formats including WAV and Ogg/Vorbis (among others) but not MP3. It is however possible to pipe the output of a program into Pi-FM-RDS. For instance, this can be used to read MP3 files using Sox.

The Broadcast System of Tibaŋsim is the main user interface for the End-User. The system reads the audio files from the file storage system of the Voice Input Module and broadcasts them on a loop on FM at 107.9MHz. This frequency was chosen because, firstly, it is at the very end of the used frequencies for FM Stations and also because it was found to be the least close frequency to the registered FM Stations [12] in Northern Ghana.

---

[11] http://asterisk-service.com/en_US/page/chan-dongle-modems

[12] https://en.wikipedia.org/wiki/List_of_radio_stations_in_Northern_Region

Monitoring System: BashOverSMS Monitoring of deployed ICT Systems are difficult but at the same time, it is very desirable to keep track of its operation status[24]. Many monitoring tools exist, some even designed with rural deployments in mind, but in some low resource environments, it becomes impossible to implement these, as they rely on internet connections[25].

The Monitoring System of Tibaŋsim (BashOverSMS) uses the existing GSM connection to send internal measurements/information to a pre-defined number for monitoring purposes. The information, which includes device temperature, CPU and IO utilization, number of running processes, uptime and the names of the available recordings from the Kasadaka file system, is sent at 30 minute intervals. An analysis of these results give an indication to the average and highest temperature of the device (critical due to the climate of the region), the software load on the device (will inform on future adaptations) and keeping track of recorded voice fragments.

In addition, BashOverSMS, receives commands sent from a pre-defined number and executes them on the system. This gives the ability to remotely make software-based system changes, modify the measurements and information being send, delete outdated voice fragments, among other things.

Setup and Testing Setup and testing was carried out at the University for Development Studies in Tamale, Ghana in conjunction with experts from the CSIR-SARI and Internet Society, Ghana Chapter. Setup involved the assembling of the hardware components and installation of the developed system. Testing involved call-ins by stakeholders to test the Voice Input, tuning in on various radio-enabled devices to test the Broadcast System (quality and range) and test of the Monitoring System by retrieving the various measurements over SMS and also sending commands via the BashOverSMS module.

4.2 Deployment

Deployment entailed a road-trip to 5 communities in the Salaga District of Ghana (see Section 3.1). CSIR-SARI, together with an Agricultural Extension Agent from the Ministry of Food and Agriculture had pre-informed the selected communities of the deployment visits. At each community, the system (as a whole) was re-introduced to community members. Most were aware of the system due to collaborations in the context analysis and user-centered design process. A community member (pre-selected by community members) worked with the team to place the hardware in the most optimal location (with respect to safety, GSM reception and FM Broadcast coverage). Community members then tuned in on their various FM-enabled devices to hear the broadcasts. This was used as a beta test where more data was collected to inform on further changes.

5 Evaluation and Monitoring

We present an analysis of the System Usability Scale survey and an analysis of data obtained from the Monitoring System

5.1 User Evaluation

SUS Evaluation Setup The System Usability Scale (SUS) is designed to obtain subjective feedback on overall usability and user satisfaction[26]. The SUS involved the administering of the test to all 106 participants after their use of the system. The following questions were asked and participants responded on a scale of 1 (strongly disagree) to 5 (strongly agree);

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

It is important to note that translations (in the right context) were necessary to effectively administer the SUS as it has been found that there is a possibility of a lack of comprehension in some of the SUS questionnaire items for even non-Native English speakers [27].

Items 1, 3, 5, 7, and 9 are positively worded and items 2, 4, 6, 8, and 10 are negatively worded. Apart from the 10-item SUS Score, using factor analysis, the SUS is able to provide additional information via two sub-scales: an 8-item "Usability" and 2-item "Learnability" scale [27][28].

SUS Results For reliability analyses of the data, the absolute ratings (Questions 2, 4, 6, 8, and 10 were recoded so that all scales had 1 as the negative and 5 as the positive) for the 10 statements were used to calculate Cronbach's alpha[29]. The SUS showed good internal consistency (alpha = 0.743)

Table 5. System Usability Scale Score

SUS Score	80.50
Learnability	71.90
Usability	82.60
Standard Deviation	16.08
Cronbach's Alpha	0.74
Adjective Rating	Excellent

For every odd-numbered item above, we subtracted one from the user response (x - 1). For every even-numbered item above, we subtracted the user response from 5 (5 - x). This scales all values from 0 to 4 (with four being the most positive response). We then multiply each response by 25; this converts the range to a 0 to 100 scale. The average score of the averages of all calculated responses gives us an SUS Score of 80.52 (an Adjective Rating[30] of "Excellent") with a Standard Deviation of 16.08. We also calculate Learnability from Questions 4 and 10, giving a value of 71.93, and Usability from the remaining 8 questions, giving a value of 82.67 (See Table 5).

The high scores for SUS, Learnability and Usability, indicates a high quality of end-user's experience with Tibaŋsim and the ability to utilize it with little to no prior training or help.

5.2 Monitoring

The Monitoring System of Tibaŋsim provided data on device temperature, CPU and IO utilization, number of running processes and uptime of the five (5) deployed systems. We present data collated from the Monitoring System for a period of 20 days (average of one SMS every hour), from the 23rd of October, 2019 to the 11th of November, 2019

Table 6. Analysis of Monitoring System Data

Community		R1	R2	R3	R4	R5
Device Temp (°C)	Mean	63.64	63.66	63.99	63.56	63.67
	Max	81.70	80.60	81.10	77.40	80.60
CPU/IO Utilization	Mean	0.41	0.40	0.41	0.39	0.38
	Max	1.54	2.03	2.03	1.46	1.89
Processes	Mean	7.53	7.40	7.62	7.49	7.47
	Max	13	13	13	12	12
Average Uptime/Day (Hrs)	Mean	16.83	17.16	16.59	16.39	17.01
	%	70.10	71.51	69.11	68.28	70.89

Device Temperature The average atmospheric temperature in northern Ghana in October is about a min of 22°C to a max of 30.6°C, rising by March to an average of 25°C (min) to 39.7°C [13]. These high temperature values makes device heating a large concern with regards to hosting in a rural setting.

All Raspberry Pi models perform a degree of thermal management to avoid overheating under heavy load. The System on a chip (SoCs) have an internal temperature sensor, which software on the GPU polls to ensure that temperatures do not exceed a predefined limit; this is 85°C on all models. For Raspberry

[13] https://www.darksky.net/

Pi 3 Model B+, the PCB technology has been changed to provide better heat dissipation and increased thermal mass [14]; one vital reason for the use of this model over its predecessor (Raspberry Pi 3 Model B). Heatsinks were also installed on each device, but no fans.

The Monitoring System uses a command that can provide an accurate and instantaneous reading of the current SoC temperature, as it communicates with the GPU directly, *vcgencmd measure_temp*, to retrieve the device temperature. For the period of 20 days, from hourly measurements, we recorded an average temperature of 63.64°C, 63.66°C, 63.99°C, 63.56°C and 63.67°C respectively for each community, with a maximum device temperature of 81.7°C, 80.6°C, 81.1°C, 77.4°C and 80.6°C (See Table 6).

The average and maximum temperatures measured from the devices indicate no thermal issues and are well below the high of 85°C.

CPU and IO utilization On Linux, load averages are (or try to be) "system load averages", for the system as a whole, measuring the number of threads that are working and waiting to work (CPU, disk, uninterruptible locks). In short, it measures the number of threads that aren't completely idle with the advantage that this includes demand for all resources [15].

In a Single-Core CPU, a load of 0.0 means there is no utilization of resources at all and a load of 1.0 means utilization is at full capacity. Beyond 1.0 would indicate a backlog of processes waiting to run. However, in a Quad-core CPU (like the Raspberry Pi B+), the load is relative to the number of processor cores available; a load of 4.0 means utilization is at full capacity [16].

The Monitoring System uses *cat /proc/loadavg* to read the load averages over the last minute, the last five minutes, the last 15 minutes. An average of these was taken by hourly measurements over the 20 day period. We recorded an average utilization of 0.41, 0.40, 0.41, 0.39 and 0.38 respectively for each community with a maximum utilization of 1.54, 2.03, 2.03, 1.46 and 1.89. (See Table 6)

The average and maximum CPU and IO utilization are well below the capacity of 4.0. This indicates the various components of Tibaŋsim require little processing power and are efficiently utilizing resources even with continuously looped broadcasts over FM and call-ins to the system.

Uptime The availability of a system is largely dependent on its uptime. The formula given for the calculation of availability is

$$\frac{uptime}{uptime + downtime} \qquad [31] \qquad (1)$$

[14] https://www.raspberrypi.org/documentation/hardware/raspberrypi/frequency-management.md
[15] http://www.brendangregg.com/blog/2017-08-08/linux-load-averages.html
[16] https://scoutapm.com/blog/understanding-load-averages

For a system hosted in a low-resource community, this could be a major issue due to unreliable electricity.

The Monitoring System uses *uptime* to read the uptime of each device over the 20 day period. A calculation yielded the maximum uptimes registered for each day. The average of this was calculated to give values of 16.83 hours, 17.16 hours, 16.59 hours, 16.39 hours and 17.01 hours respectively for each community with a calculated availability of 70.10%, 71.51%, 69.11%, 68.28% and 70.89%. (See Table 6)

Upon further investigation, the average downtimes of 7.18 hours, 6.84 hours, 7.41 hours, 7.61 hours and 6.99 hours respectively, turned out to be during the night (between 10pm and 7am), where the local hosts powered-down the devices.

5.3 Content Relevance and Quality

The Context Analysis and Needs Assessment (see Section 3.2) of the methodology used necessitated the solicitation of required content from the end-users. In fact, this was one of the starting points of the project. Being involved in the development process and being gradually becoming aware of the possibilities, end-users, as well as stakeholders (who work close in-hand in the rural communities) were able to clear specify the type of information that would be relevant to them. Furthermore, post-deployment, empirical data was gathered on the type of content end-users would find relevant (see Appendix A). Notable among information considered relevant in the research area are; Crop Farming Practices, Market Prices, Information on seed, Climate Information and Placing ads for sales of produce (see Section 3.3). With regards to quality, stakeholders (like CSIR-SARI) are already mandated officially to solicit, create and disseminate content, in areas such as agriculture. Of note is information from the World Wide Web, and example being climate information; this requires more technical work to enable automated updates to the system and was implemented as a separate integrable system dubbed Mr. Meteo [33]

5.4 Cost-effectiveness and Affordability

Based on our context analysis, Cost-effectiveness was of utmost importance and therefore considered a Non-Functional Requirement (see Section 3.3.5). As such, design choices were made for low-cost hardware (see Section 3.4.1) and open-source software (see Section 3.4.2). The system is also designed to enable rapid and little to no cost setup (see Section 3.4.3). For purposes of sustainability, it is imperative that running costs and affordability are catered for and as such, design choices are made to facilitate low-cost maintenance and affordability to end-users. Furthermore, a business model was designed (see Section 3.4.5) to facilitate the project's financial sustainability. The Internet Society is in the process of funding the next iteration of the project, which will establish a financially-sustainable project with a business entity and which will expand the system to over 100 communities.

6 Discussion

Development and/or deployment of ICT systems for low-resource areas comes with a myriad of challenges[5], some general and others pertaining to the particular system. This is important to any study, being that these are issues that are not always readily apparent. In this section, we discuss a few issues gleaned from the study which apply to most low-resource environment deployments

6.1 Remote Communities

Development of systems for low-resource environments with the methodology used requires physical visits (possibly several) to communities. Some communities are remote, with bad road access, making the required multiple visits tedious. This, on the contrary, is the very reason why information access for such communities is vital.

In this project, all communities were remote, with bad road access, but visits were necessary for information elicitation and deployment. However subsequently, it will be possible to deploy with the help of Agricultural Extension Agents who, as part of their existing jobs, visit these communities from time to time.

6.2 Poor 3G/GSM Reception

Information dissemination through ICTs rely on telecommunications networks, but unfortunately, many rural communities lack sufficient access. In some rural communities in Ghana, there is little to no 4G, sparse 3G and patchy GSM reception.

This needs to be taken into account to build systems that do not require constant internet access, high bandwidth, constant uptime, etc. The details will depend largely on the particular community.

Some communities visited for Tibaŋsim's deployment had very bad GSM reception; this led to the change of a few communities for the pilot. We found that there were some locations within those communities with good GSM coverage, but were not ideal for the placing of the hardware. In the next iteration of development, we are considering an outdoor, waterproof enclosure coupled with solar-power supply. In addition, we are considering GSM boosters to augment the reception to the device.

6.3 Unavailability of hardware

In many developing countries, hardware needed to build ICT systems may not be readily available. This may not be a major issues during the pilot process, but considering the sustainability of such projects (See Section 3.4), it is important to ensure that local developers are able to obtain the hardware required. As such, hardware requirements are not trivial.

For Tibaŋsim, the required hardware (Raspberry Pi 3B+ and Huawei 3G Modems) had to be imported into the country due to its unavailability in Ghana. This caused some delays with the initial pilot. However, the above hardware is readily available in many places around the world and local developers with prior planning should be able to obtain the hardware.

6.4 FM Broadcast Range

This is a project specific issue, but we thought worth mentioning;

The FM broadcast range of the Raspberry Pi 3B+ with a simple wire antennae is about a 120 Meters radius. As much as this covers enough of the community to be available to community members, the ideal would be a wider range to cover the entire community and to cater for larger communities. The next iteration will consider boosting the range of the FM transmission. This however would require liaising with the National Communications Authority[17] in Ghana once transmissions begin to exceed official community ranges and/or becomes a commercial product.

It should be noted that innovative ICT solutions such as this one can have legal implications with have to be addressed especially due to the need for financial sustainability which makes the innovation a commercial product.

7 Conclusion

Information access remains a problem in many parts of the world[1]. Developing countries, like Ghana, have numerous rural communities that have little access to up-to-date and relevant information[2]. Telecommunication infrastructure is lacking in these communities and limited, mostly, to GSM reception. Rectifying the issue of infrastructure alone unfortunately does not solve the problem due to other major issues like unaffordability of internet-capable device and internet and voice services, low levels of literacy and unavailability of relevant content further compounds the issue[3].

Available literature points us towards the use of 'technology-in-use'[9]; in the case of Ghana, mobile telephony and FM radio, concentrating on voice technologies[14] and local languages.

This paper has presented a case study of an appropriate ICT4D methodology[5] in the development of an ICT4D system which is hosted and used in low-resource environment. We presented empirical data from rural communities and other stakeholders, which was used iteratively to design a low-cost, voice-based information system for rural communities meeting the contextual requirements and operational goals of the various stakeholders.

We also present a proposed business model from brainstorming with stakeholders. The business model uses the e^{3}value ontology[23] to present an appropriate financial interaction pertaining to the system that would aid its sustainability.

[17] https://www.nca.org.gh/

Furthermore, a System Usability Score (SUS)[26] test was administered to 106 community members from five (5) communities where the system was deployed and we presented an analysis of the SUS, Usability and Learnability scores which indicate that the requirements of the end-users were met and the system is easily used and learned.

We further presented system data, gathered through an innovative remote monitoring system. The data showed deployed devices indicated no thermal issues and are well below the high of 85°C, CPU and IO utilization are well below the capacity of 4.0 indicating good use of processing power and resources even with continuously looped broadcasts over FM and call-ins to the system. Analysis of the availability of the system also showed that local hosts powered-down the devices during the night (between 10pm and 7am), but broadcasts were available during the day.

Information is a very important commodity for development[32]. As such, bridging the digital divide is vital, not only to developing countries, but to the world, as the successes of attaining the Sustainable Development Goals (SDGs) [18] will benefit the planet as a whole. The process of systems development for low-resource regions is therefore critical to the successfully attaining SDGs. This process is not trivial and requires an appropriate methodology that is collaborative, user-centered, and iterative. This aids to fix issues that exist for the stakeholders and end-users as opposed to fixing perceived problems.

The Tibaŋsim project shows this development process for low-resource areas practically and hopes to serve as a guide for future projects.

The authors thank Christophe Guéret for the original Kasadaka idea and the University for Development Studies ICT for Food and Water in Ghana team led by Saa Dittoh. We also acknowledge the contributions of Kay Kutah Wilhelm (Savanna Agricultural Research Institute), The Internet Society Ghana Chapter, and The Internet Society for funding the pilot project. The authors also thank Chris van Aart, Amadou Tangara, Chris Reij, Stephane Boyera, Gossa Lô, Julien Ouedraogo, Matthieu Ouedraogo, Mary Allen, Nana Baah Gyan, Aman Grewal, Yacouba Sawadogo, Stefan Schlobach and many others for their contribution to this continuing research project.

References

1. Worldwide digital population as of January 2020, Published by J. Clement, Feb 3, 2020
2. The State of the Internet Around the World, Mar 11, 2019. Retrieved March 2020 from https://www.statista.com/chart/17322/global-internet-access/
3. S. Schmida, J. Bernard, T. Zakaras, C. Lovegrove and C. Swingle, "Connecting the Next Four Billion: Strengthening the Global Response for Universal Internet Access," USAID, Dial, SSG Advisors, Seattle, 2017.
4. A. Estache and M. Vagliasindi, "Infrastructure for accelerated growth in Ghana: Investment needs, Policies and Institutions," World Bank, 2007.

[18] https://sustainabledevelopment.un.org/

5. A. Bon, H. Akkermans and J. Gordijn, "Developing ICT Services in a Low-Resource Development Context," Complex Systems Informatics and Modeling Quarterly, pp.84-109, 2016.
6. I. Fosu, "Exploring the potential of wireless technologies to accelerate universal Internet access in Ghana," Telecommunications Policy 35, pp. 494-504, 2011
7. F. Dittoh, C. van Aart and V. de Boer, "Voice-based marketing for agricultural products: a case study in rural Northern Ghana," in Sixth International Conference on Information and Communications Technologies and Development, New York,2013.
8. E. Luxton, "4 billion people still don't have internet access. Here's how to connect them," World Economic Forum, 2016.
9. R. Heeks, The ICT4D 2.0 Manifesto: Where Next for ICTs and International Development?, DOI:10.13140/RG.2.2.21400.14086, July 2009
10. International Telecommunication Union Statistics, Retrieved March 2020 from http://www.itu.int/ITU-D/ict/statistics/
11. ESOKO, Retrieved March 2012 from http://www.esoko.com
12. Google Trader, Retrieved March 2020 from http://www.google.com.gh/local/trader
13. Stéphane Boyera, The Mobile Web to Bridge the Digital Divide?, W3C, 2004
14. Victor de Boer et al., Radio Marché : Distributed Voice and Web-interfaced Market Information Systems under Rural Conditions, CAISE, 2012
15. James Topham, “Making Waves” Radio Based Learning Brings Education to Young Girls in the DRC, July 2016. Retrieved March 2020 from https://warchild.ca/congo/making-waves-radio-based-learning-brings-education-young-girls-drc/
16. VOice-based Community-cEntric mobile Services for social development (http://www.mvoices.eu/)
17. André Baart et al.: Affordable Voice Services to Bridge the Digital Divide: Presenting the Kasadaka Platform, in Selected Papers from the WEBIST 2018 International Conference, Springer LNBIP Book Series, Berlin, Germany, 2019
18. N. C. Authority, "Quarterly Statistical Bulletin on Communications in Ghana,"Communications for Development, Accra, 2019
19. Likert, Rensis, "A Technique for the Measurement of Attitudes". Archives of Psychology, 1932
20. Oliver Mattos and Oskar Weigl, Turning the Raspberry Pi into an FM Transmitter, Imperial College Robotics Society, 2012
21. FM-RDS transmitter using the Raspberry Pi, https://github.com/ChristopheJacquet/PiFmRds
22. Gammu, https://wammu.eu/gammu/
23. How to model and analyze a value model, https://www.thevalueengineers.nl/tutorials/model-analyze-value-model/
24. Otto Dostál, ICT Systems Monitoring: New Approaches, Methods and Tools in ICT Systems Monitoring, February 13, 2012
25. Jing Cai, Kun Liu, "Constructing a Remote Monitoring and Control System Based on 3G Mobile Networks", Wireless Communications Networking and Mobile Computing 2009. WiCom '09. 5th International Conference on, pp. 1-4, 2009.
26. Brooke J. SUS-A quick and dirty usability scale. Usability evaluation in industry. 1996 Sep 1;189(194):4-7.
27. Finstad K. The system usability scale and non-native English speakers. Journal of usability studies. 2006 Aug 1;1(4):185-8.
28. Sauro, J. A practical guide to the system usability scale: background, benchmarks best practices. Denver, CO: Measuring Usability LLC. 2011

29. Gliem, Joseph A., and Rosemary R. Gliem. "Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales." Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education, 2003.
30. Bangor A, Kortum P, Miller J. Determining what individual SUS scores mean: adding an adjective rating scale. Journal Usability Study. 2009;4:115–124.
31. Stearley, Jon. "Defining and measuring supercomputer Reliability, Availability, and Serviceability (RAS)." In Proceedings of the Linux clusters institute conference. 2005.
32. Allen, Beth. "Information as an economic commodity." The American Economic Review 80, no. 2 (1990): 268-273.
33. Francis Dittoh, Victor de Boer, Anna Bon, Wendelien Tuyp, and André Baart. 2020. "Mr. Meteo: Providing Climate Information for the Unconnected.". 12th ACM Conference on Web Science (WebSci '20 Companion), July 6–10, 2020, Southampton, United Kingdom