# Learnings on the Future of Applying the Internet of Things (IoT) for Climate Change Adaptation in Rwanda

Lessons Learnt from the 'IoT for Climate' Project in Rwanda

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## **Executive Summary**

## Background

Disaster risk is increasing globally, largely due to a growing exposure of people and assets to natural hazards. Between 2006 and 2015, there was an annual average of 376 disasters triggered by natural hazards, affecting about 224 million people and causing over 69,000 deaths annually.<sup>1</sup> More specifically, intense climate-related disasters have been on the rise worldwide. Between 1995 and 2015, 90% of disasters were caused by floods, storms, heatwaves and other weather-related events. In total, 6,457 weather-related disasters were recorded, claiming 606,000 lives, with an additional 4.1 billion people injured, left homeless or in need of emergency assistance.<sup>2</sup> Floods have accounted for the majority of weather-related disasters worldwide, striking in Asia and Africa more than in other continents. Droughts also account for significant disasters, and are associated with widespread agricultural failures, loss of livestock and water shortages. In total, more than one billion people have been affected by droughts in the past 20 years.<sup>3</sup> Droughts affect mostly Africa, with 77 droughts recorded in East Africa alone. In particular, droughts put at risk the lives and livelihoods of vulnerable populations such as smallholder farmers, who account for 70 percent of Africa's population and whose agriculture depends on rainfall. This in turn affects the population as a whole considering that smallholders produce about 80 percent of the food in Sub-Saharan Africa.

In Rwanda, water and climate related issues remain a significant impediment to the country's green growth strategy and pose direct risks for vulnerable populations, such as rain dependent smallholder farmers. The country is highly prone to hazards, including drought, landslide, flood, earthquake and windstorms. Over 157,000 people are vulnerable to drought, about 7,500 are vulnerable to landslide and over 5,000 houses are vulnerable to windstorm, while forest and landscape degradation and climate change increase the risk and severity of disaster. In particular, the districts of Kayonza, Gatsibo, Kirehe, Nyagatare, Rwamagana, Ngoma and Bugesera in the Eastern province are likely to experience severe drought. On the other hand, the highlands of the Congo-Nile Ridge in the Western, Southern and Northern provinces are prone to landslide.

Accurate climate and weather information is critical for managing climate related risks such as droughts and floods, early warnings and fast response; however, micro level data is very difficult to collect with traditional meteorological stations. African observation networks are still very sparse and unevenly distributed, and there is not enough data to inform decisions in water management and climate change adaptation. Weather stations in Africa are spread out over large distances, most being found in northern and southern Africa. The lack of communication occurs within countries and the region as a whole, creating data gaps at multiple levels.

In Rwanda, climate related data is collected and analyzed by Meteo under the Ministry of Environment. Meteo's observational network platform contains automatic weather stations but also many manual weather stations. In the manual stations, one staff or volunteer observer per station

<sup>&</sup>lt;sup>1</sup> Guha-Sapir, D., Hoyois, P., Wallemacq, P., and Below, R. (2016). *Annual Disaster Statistical Review 2016: The numbers and trends*. Brussels, p.1

<sup>&</sup>lt;sup>2</sup> CRED and UNISDR (2015). *The Human Cost of Weather-Related Disasters* 1995-2015.

<sup>&</sup>lt;sup>3</sup> Ibid, p. 16

writes down the record for the day and sends the data as a monthly report by phone or paper form. Thus, the process is slow and leaves room for human error. This can delay early warning mechanisms and in the face of large scale disaster, prove inefficient to provide first-hand scoping information and moreover lead to loss of data. Meteo and other relevant stakeholders and users of climate information have expressed the need for more targeted and speedy information, especially for disaster risk reduction and agricultural planning.

#### **Project objectives and scope**

Considering the pressing challenge of climate-related risks in Rwanda and in the region as well as the need for more accurate climate and weather data and information, Meteo Rwanda and UNDP piloted the project "Internet of Things (IoT) for Climate Change" (or IoT for Climate). The pilot project consisted of two phases. Phase One was implemented in collaboration with University of Tokyo and with seed funding from UNDP Innovation Facility. This Phase focused on IoT for Climate Change and Water Management to test a new real-time microclimate data collection methodology using IoT technology in three small-scale sites. Phase Two was implemented in collaboration with RISA and funding from Noreps and focused on IoT for Climate Early Warning and Humanitarian Response.

UNDP understands that for innovation to happen there needs to be a big investment in learning, which is why the pilot project focused on testing different aspects throughout the entire value chain, including the collection, assimilation, distribution and usage of climate data. Through this process the project team was able to gain a clear understanding of the needs of the smallholder farmers, vulnerable populations, meteorological agency and other stakeholders, as well as to capture key learnings that would set the direction for further scale up of this initiative.

The project aims to develop new technologies and applications that can sustainably address existing and future emerging climate issues through "real time" environmental data collection, analysis, dissemination and applications. The project also aims to transfer technology to strengthen the capacity from upstream sensor engineering skills to downstream data application on using IoT for climate and environmental issues, creating space for new business and job opportunities in Rwanda.

The project piloted the IoT concept by setting up sensors and open-source data relay boxes in Kayonza District in the Eastern Province of Rwanda where drought and water shortage are persisting issues. Data such as soil moisture, temperature and humidity was collected real time, and applications were developed for analyzing and disseminating the climate data in an effective and understandable way through close consultation with potential users such as the vulnerable population. While the initiative focused on weather related issues, such as measurement of soil temperature, and humidity, the technology could potentially be applied to other environmental data collection including forestry, biodiversity and pollution.

This initiative is further linked to the government's efforts to expand Rwanda's commitment to the "Internet of Things" (IoT). It is likewise hoped that the technologies and applications developed under this initiative in Rwanda could be scaled geographically to other Sub-Saharan countries.

#### **Innovation approach**

UNDP placed a strong emphasis in using an innovative approach for the IoT for Climate project, integrating innovation throughout the entire project cycle.<sup>4</sup> With the support from the Innovation Facility, the project team was encouraged to engage in a process of testing and learning as well as to embrace failure as a necessary step for success. Through a continuous process of empathizing, ideating, prototyping and testing, the team was able to gather learnings that are crucial for pivoting and redefining the direction the initiative must take for further scale up. The pilot project was established as a first phase of a broader initiative that aims to leverage the potential of IoT technologies and applications for climate adaptation.



#### Innovation approach used for the IoT for Climate Initiative

The project focused on a strong **user-centered approach**. Moving away from the notion of "beneficiary", the project focused on understanding the needs of the "users" it was trying to serve. The project also used a **collective innovation approach** by engaging a wide range of stakeholders from the beginning and designing the project in a collective manner. The project further used a **lean startup approach**, by which ideas were prototyped and tested continuously. From selecting the site all the way to developing the applications for the end users, there was always a process of testing and learning. Lastly, the project made sure to look at the **scalability and sustainability** of the initiative. As part of the pilot project, partnership workshops were designed to bring together key stakeholders and discuss the next steps IoT for Climate Initiative. This report serves to document strategies for scale up as well as to reflect on the process of the pilot project so far and explore ways to make the project sustainable.

<sup>&</sup>lt;sup>4</sup> The "Project Cycle Hackers Toolkit" was useful for integrating innovation in the project design and implementation and wrap up.

#### Key project achievements:

- Key stakeholders, including Meteo Rwanda, RAB, RWFA, MIDIMAR, REMA, and Kayonza District officials were engaged in the design and implementation of the pilot project and are supportive of the initiative and its future scale up.
- A strong understanding of the needs of vulnerable populations and key stakeholders was attained through extensive stakeholder engagement, user interviews and field visits to Murundi, Ndego and Rwinkwavu Sectors in Kayonza District.
- 12 IoT sensors were assembled, set up and maintained in Kayonza District to collect real-time data such as soil moisture, temperature and humidity. The process involved trainings, stakeholder workshops and field visits.
- A data collection server was established: data from IoT sensors was collected and sent to the WiredIn server using WiFi.
- Capacity was built through "learning by doing" University of Tokyo and Meteo staff trained TCT graduates on IoT sensors assembly, set up and maintenance.
- 66 young programmers and scientists came together to design IoT applications for climate change adaptation during the Phase One Design-a-thon for Climate. Five teams were awarded for their innovative solutions.
- Winning prototypes of the Design-a-thon were further developed and tested during Phase Two of the project. An application to disseminate information and advice to farmers is ready to be piloted. An API was installed in Meteo's server, improving access to climate data and allowing developers to build new applications. A volunteer observers application was developed and is ready for roll out, which will help digitize the recording of data at the manual weather stations.
- Gaps along the climate information for early warning were clearly identified and documented and solutions were prototyped through the Phase Two Hackathon event.
- 33 young programmers and developers came together to prototype and test solutions at the Hackathon for Climate Early Warning. Solutions include low-cost sensors to collect soil moisture data, platforms to help MIDIMAR quickly identify and visualize at risk areas, platforms to automate the flow of communication between Meteo and MIDIMAR, and applications to disseminate early warning information to the population.
- 38 participants from stakeholder institutions were trained during the Hackathon side event sessions on IoT technologies, IoT weather stations and IoT for Early Warning.
- A partnership workshop was conducted and strategies for scale up were identified (see strategies 2.2)

#### What is the IoT for Climate Value Chain?

In order to improve the climate information flow for better climate adaptation, there is a need to work along the entire value chain, from data collection to data analysis, dissemination and usage. The below graph shows the pathways that were identified on each area of the chain.



#### **User profiles and needs**

"Climate change is a big challenge for us because we sometimes sow seeds but it changes. Some days they announce that on a given day it will rain and it doesn't rain like they predicted. Nowadays it is the most confusing... At Mucucu [the cell next door] they told us it has rained but it didn't rain here... Not being able to get correct information we end up sowing contrary to the forecast and loose crops." (Esther - Farmer of Murundi Sector)

The first phase of this pilot project identified as users the farmers in rural areas who need to utilize daily weather forecasts better in order to secure harvest and be better prepared to climate change adaptation. Phase two of the project identified as users the broader population vulnerable to disasters including flood, landslide and drought and who are in need of early warning to evacuate or prepare. Based on a user-centered approach, the pilot project did a thorough assessment of both users and their needs through user interviews, field visits and by engaging with stakeholders and experts who provided more insights into the problem. From the initial consultations and interviews with users and stakeholders from Kayonza District what stood out as a clear finding was the need for timely and accurate climate information specific to the local (cell) level as well as the need for an Early Warning system, by which local communities could be alerted before a disaster occurs.

#### **Stakeholders**

Engagement of key stakeholders is crucial to ensure the success and sustainability of the IoT for Climate project. A wide range of stakeholders were involved during the pilot project to ensure that the technologies and applications are relevant and meet the needs of the users. These stakeholders contributed to the pilot project by sharing expertise, providing technical advice and data, and sharing insights into the community needs.

UNDP and Meteo Rwanda were the lead organizations implementing this pilot project, with the support University of Tokyo, Noreps and RISA. Other key stakeholders such as MIDIMAR, RAB, RWFA and MINALOC provided expertise on the current challenge of weather data collection and needs for effective disaster risk management and agricultural planning. The local community such as officers from Kayonza District, sector agronomists and smallholder farmers provided specific insights into the needs of the community at the district, sector and cell levels. For the next phases and to scale up this initiative, other key stakeholders will need to be involved in addition to those engaged during the pilot phase (as shown in the below diagram).

#### International stakeholders Development partners (e.g. JICA, USAID, NOREPS, Red Cross, World Bank, ADB, SIDA, KOICA, DFID); UN agencies (UNDP, FAO, WFP, UNHCR, ITU)

#### National stakeholders

MIDIMAR, MINIRENA, MINALOC, MINAGRI, MITEC, MINEDUC, MoIT, Meteo, RAB, RURA, RWFA, REMA, RDB, RISA, NCST, CGIS/UR

## Local community

Districts and sectors, local NGOs, District officials, Sector agronomists, Farmer facilitators and promoters

#### Key stakeholders Meteo Rwanda, UNDP, MoE, MIDIMAR, RAB, RWFA, REMA, District and

Sector Officers

## **Opportunities and potential of IoT for climate change adaptation**

Opportunities for this initiative in Rwanda include low-cost technologies, increased capabilities to process and analyse big data, increased internet penetration and mobile connectivity, commitment of the Government of Rwanda to ICTs and IoT, and strong support from stakeholders represented by Meteo Rwanda. By leveraging these opportunities, the IoT for Climate initiative can have a meaningful impact in reducing the vulnerability to climate change. Better climate data collected through IoT technologies can lead to more timely and accurate climate information that is used for better agricultural planning, Early Warning and Disaster Risk Management, water management and to address other environmental concerns. Moreover, the initiative has the potential of strengthening the IoT industry overall, contributing to "Made in Rwanda" technology and promoting employment and business opportunities.



Potential of IoT for Climate Change Adaptation

## Main challenges

When using IoT technologies and applications for climate change adaptation in the context of Rwanda, there are various challenges and considerations that need to be taken into account, which include those in relation to the collection, dissemination, distribution and usage of climate related data.

In terms of data collection, there is a trade-off between small scale low-cost IoT devices and more complex automated weather stations that meet WMO standards. Using small-scale IoT devices could potentially be deployed in more locations, helping collect more localized data in Rwanda. However, there are some drawbacks that need to be considered. The monetary cost of small-scale devices with a limited number of sensors is indeed markedly lower than that of the weather stations, yet they do not have the full array of sensors of a weather station and are not WMO compliant. Other main challenges related to IoT technologies in general include security concerns; durability, maintenance and safety of sensors; electricity stability and internet connectivity.

On the data assimilation aspect, main challenges have to do with the existing capabilities in place to actually harness granular data from IoT technologies to improve the weather forecasts. Other challenges relate to the compliance of the data collected with WMO standards as well as the complexity of using the data for drought predictions. On the data accessibility side, the main

challenges relate to ensuring accessibility to Meteo's data. The API server will need to be running and the network needs to be properly configured.

Lastly, on the usage end, the main concerns relate to making sure that climate data is turned into usable reliable climate information. Furthermore, there needs to be the awareness and skills for users, such as smallholder farmers and vulnerable populations, to use new climate information products and services.

#### Scale up guideline for IoT for Climate

The pilot phase focused on testing different components along the IoT for climate value chain. Based on the learnings from Phase One and Two, some guidelines are suggested for the scale up of this initiative and outputs and activities are proposed for the next phase. More details are found under chapter 3.2.

Guideline #1: Scale up solutions after piloting and testing (see below graph)

**Guideline #2:** Focus the strengthening of Meteo Rwanda in data quality control, assimilation and coordination

**Guideline #3:** To fully benefit from the concept of IoT, leverage on the private sector and entrepreneurs ecosystem

Guideline #4: Strengthen partnerships with other existing projects and stakeholders



Solutions to improve climate information prototyped during Phases I and II

#### **Structure of the report**

This report consists of three chapters as follows:

Chapter One is an introduction the IoT for Climate initiative. The chapter includes background information on Rwanda and the region, an overview of the pilot project and the innovation approach used. Chapter Two focuses on key findings from the pilot project, which include the IoT for Climate value chain, user profiles and needs identified, key stakeholders around climate information and the opportunities and challenges of using IoT technologies for climate. Finally, Chapter Three looks into lessons learned of the pilot project and explores strategies for scaling up the initiative.

# **Chapter 1: Introduction**

## 1.1 Background

## 1.1.1 Context in Rwanda

Rwanda is facing ongoing challenges in water management due to increasingly unpredictable rain patterns and drought, complex landscape, and increasing stress on land with high population density. Water and climate related issues remain a significant impediment to the country's green growth strategy and pose direct risks for vulnerable populations, such as rain-dependent smallholder farmers. The country is highly prone to hazards, including drought, landslide, flood, earthquake and windstorms. Over 157,000 people are vulnerable to drought, about 7,500 are vulnerable to landslide and over 5,000 houses are vulnerable to windstorm, while forest and landscape degradation and climate change increase the risk and severity of disaster.

According to The National Risk Atlas of Rwanda, over the last decade the frequency and severity of natural disasters, particularly caused by floods and droughts, have significantly increased. In particular, the districts of Kayonza, Gatsibo, Kirehe, Nyagatare, Rwamagana, Ngoma and Bugesera in the Eastern province are likely to experience severe drought. About 157,000 tons of major crops are vulnerable to severe drought in Season  $B_{,}^{5}$  with banana and cassava being amongst the most vulnerable crops. On the other hand, the highlands of the Congo-Nile Ridge in the Western, Southern and Northern provinces are prone to landslide. About 40 percent of the population is actually exposed to landslide at moderate to very high slope susceptibility.

Given the high level of exposure to different hazards, the country could incur in huge economic losses from disasters triggered by such hazards. For instance, the total economic cost of vulnerable crops in the drought-prone areas is estimated at approximately 8.8 billion Rwandan francs according to both drought hazard scenarios for Season A and Season B.<sup>6</sup> These losses are concentrated mainly in the Eastern province, in particular Kayonza, Kirehe and Gatsibo, where the agricultural exposure to drought is higher.

Besides the country's exposure and vulnerability to weather variations in the past years, the country is characterized by microclimates, by which there are significant weather variations between very short distances. While one cell can receive rainfall, the neighbouring cell can be without any rain for long periods. Accurate climate and weather information is critical for managing climate related risks such as droughts and floods, early warnings and fast response; however, micro level data is very difficult to collect with traditional meteorological stations.

Presently, climate related data is collected and analyzed by Meteo under the Ministry of Environment. Meteo's observational network platform is composed of a combination of automatic and manual weather stations. A large part of the data collection is manual, with one staff or volunteer observer per manual station writing down the record for the day and sending the data as a

<sup>&</sup>lt;sup>5</sup> Rwanda has three agricultural seasons: Season A is from September to February of the following year, season B is from March to June of the same year, and season C is from July to September of the same year.

<sup>&</sup>lt;sup>6</sup> MIDIMAR (2015). The National Risk Atlas of Rwanda.

monthly report by phone or paper form. Thus, the process is slow and leaves much room for human error. This can delay early warning mechanisms and in the face of large scale disaster, prove inefficient to provide first-hand scoping information and moreover lead to loss of data.

Meteo has expressed its concern for the way data is being collected. Other relevant stakeholders and users of climate information have expressed the need for more targeted and speedy information, especially for disaster risk reduction and agriculture planning. Automating these processes and systems can greatly contribute to eliminating human error and providing consistent and reliable data. Emerging Internet of Thing technologies can be a good low-cost alternative to manual stations in countries like Rwanda.

However, initiatives relating to IoT or more generally ICTs for accurate climate data and information continue to be limited in Rwanda. These initiatives face issues such as the lack of a communication network infrastructure in rural areas; limited purchasing power and risk-adversity of smallholders; an IT industry not yet very strong and few opportunities for business expansion. A recount of few existing initiatives in Rwanda that focus on IoT for climate or on the use of technologies for collecting better climate data can be found in **Annex 1**.

## **1.1.2** The emergence of IoT technologies

The Internet of Things (IoT) refers to a sophisticated and fast-growing network of physical devices and objects embedded with sensors, electronics, software, actuators and network connectivity which enables them to collect and exchange data. An estimated 30 billion objects are predicted to be connected by 2020; and IoT is expected to affect every aspect of societies and economies in the near future.<sup>7</sup> Through IoT, sensors can be easily deployed wherever there is needed to collect specific data such as soil moisture and temperature. The collected data are stored on a server or cloud system wirelessly, and can be easily accessed through the internet or mobile phone applications by the users that need it, for instance, smallholder farmers. IoT can be a powerful tool in helping address the challenge of collecting and providing speedy and accurate micro level data, improving the decision-making of vulnerable populations.

The rapidly growing network of connected objects and devices is affecting the lives of people not only in industrial countries, but also in emerging and developing countries.<sup>8</sup> There are already many examples of how IoT is improving lives in developing contexts, particularly relevant to this report, in sectors such as agriculture and disaster risk management. The rapid proliferation is supported by how the cost of IoT technologies is low and continues to decrease. IoT sensors can be much cheaper than conventional meteorological stations and can therefore be distributed to many more locations (cells), creating a dense observational network. Furthermore, huge amounts of data collected from IoT technologies can be processed quickly and transformed into accurate and actionable information and advice.

#### System architecture

<sup>&</sup>lt;sup>7</sup> GIZ and Betterplace Lab (2015). Internet of Things. Using sensors for good: How the Internet of Things can improve lives. Berlin: BMZ.

<sup>&</sup>lt;sup>8</sup> GIZ and Betterplace Lab (2015). Internet of Things. Using sensors for good: How the Internet of Things can improve lives. Berlin: BMZ.



The above image shows the system architecture of IoT. The IoT gateway is a physical device or software program that serves as the connection point between the devices/sensors/things and the cloud platform. Based on the data stored in the cloud, multiple applications can be developed.

#### 1.1.3 Lessons learned from similar initiatives in the region

Disaster risk is increasing globally, largely due to a growing exposure of people and assets to natural hazards. Between 2006 and 2015, there was an annual average of 376 disasters triggered by natural hazards, affecting about 224 million people and causing over 69,000 deaths annually<sup>9</sup>. More specifically, intense climate-related disasters, including floods, storms, droughts, and heat waves, have been on the rise worldwide. At the same time, temperatures and rainfall, on average, are becoming more variable and more extreme. Between 1995 and 2015, 90% of disasters were caused by floods, storms, heatwaves and other weather-related events. Floods have accounted for the majority of weather-related disasters worldwide, striking in Asia and Africa more than in other continents. Droughts also account for significant disasters, and are associated with widespread agricultural failures, loss of livestock and water shortages. In total, more than one billion people have been affected by droughts in the past 20 years.<sup>10</sup> Droughts affect mostly Africa, with 77 droughts recorded in East Africa alone. In particular, droughts put at risk the lives and livelihoods of vulnerable populations such as smallholder farmers, who account for 70 percent of Africa's population and whose agriculture depends on rainfall. This in turn affects the population as a whole considering that smallholders produce about 80 percent of the food in Sub-Saharan Africa.

In this context, climate data becomes extremely important for helping smallholders cope with changes in the weather and for the population in general to be less vulnerable to disasters. Accurate climate data are essential for agriculture, weather prediction and disaster risk reduction. However, African observation networks are still very sparse and unevenly distributed, and there is not enough data to inform decisions in water management and climate change adaptation. According to TAHMO, weather stations in Africa are spread out over large distances, most being found in northern and southern Africa. The lack of communication occurs within countries and the region as a whole,

<sup>&</sup>lt;sup>9</sup> Guha-Sapir, D., Hoyois, P., Wallemacq, P., and Below, R. (2016). Annual Disaster Statistical Review 2016: The numbers and trends. Brussels, p. 1

<sup>&</sup>lt;sup>10</sup> Ibid, pp 16

creating data gaps at multiple levels. Another challenge for climate monitoring in Africa is the availability of historical data, with data being often collected on paper and not stored electronically.

Farmers traditionally have had to respond to signals they pick from nature or to weather reports they receive from the national meteorological agencies. However, these reports often offer general information that is not location-specific and that is prone to human-errors since it is collected manually and many times in paper. With weather becoming much more unpredictable, smallholder farmers heavily depend on accurate climate data in order to make better decisions and plan well.

There are various initiatives in the region that are using IoT technologies to improve climate and weather information, including TAHMO, G4AW, MUIIS and Kukua, among others. For example, TAHMO is a not-for-profit NGO based in the Netherlands, Uganda, Kenya, and Ghana that aims to support the provision of hydro-meteorological services across Africa. It operates a network of about 400 weather stations in 18 countries. In Rwanda, TAHMO has an agreement with Meteo Rwanda and recently installed 15 stations, in collaboration with Severe Weather Consult. TAHMO stations use innovative sensor technology and ICT, becoming inexpensive and robust solutions that can provide critical data to governments, scientists and farmers in real time.

Geodata for Agriculture and Water (G4AW) is a program of the Dutch Ministry of Foreign Affairs, executed by the Netherlands Space Office that aims to improve food security in Sub-Saharan Africa and Southeast Asia by using satellite-derived information. Funded by G4A2, MUIIS is an initiative that uses satellite data to support extension and advisory services to farmers in Uganda. More information about initiatives in the region that use new technologies for better climate information can be found in **Annex 2**.

#### Summary of lessons learned

The success of other initiatives in the region is heavily dependent on successful partnerships. Most initiatives support public-private partnerships, by which various partners are engaged, including government organizations, research institutes, private sector companies, NGOs, farmer cooperatives and weather data/service providers. In particular, engaging private partners has helped in bringing the innovation component to value-added services and ensuring sustainability.

A good baseline study of the demographics of the target group, user-demand, and challenges and opportunities for adoption is a necessary requirement for the success of a project as well as provides valuable information on the agricultural practices of smallholder farmers. Collecting feedback is also crucial in the product development cycle, helping understand what works and what does not, and overall improving the final product or service.

The services offered need to be economically viable. There has to be a financial model in place and the service has to be affordable for smallholder farmers. It can be free, but then it has to be sustainable through other sources. Services generated need to add value. There is not yet a market for climate information services for smallholders, which means there are still many risks. End-users may not be able to pay or may not want to pay for these services. Furthermore, climate information solutions have to be done in such a way that smallholder farmers can easily understand and use.

On the technologies to collect data, compliance with WMO standards is necessary to ensure the data is used by meteorology agencies. The maintenance of weather stations is the most challenging aspect. Stations need to be well maintained in order to ensure that reliable data continues being collected and that smallholders receive accurate climate information. On the assimilation of data, capacities need to be in place to assimilate data from different sources, including ground and satellite. In particular, the prediction of droughts is very complex and a comprehensive and integrated approach which considers many indicators needs to be in place for drought monitoring and early warnings.

Capacity building is an important component in these climate data initiatives. Capacities need to be built for the maintenance and repair of technologies such as weather stations as well as for the use of climate information services.

Creating a sense of ownership is essential for the sustainability of the initiatives, however, this can be very costly and time consuming. Engaging relevant stakeholders, such as the national meteorological agencies, and making agreements may require more time and resources, but in the long run contributes to the success of the initiative. To reduce the vulnerability of smallholder farmers and the population as a whole through initiatives like the above mentioned ones there is a need for active advocacy and knowledge exchange to share success stories and learn from mistakes.

## **1.2 Innovation approach and methodology**

UNDP placed a strong emphasis in using an innovative approach for the IoT for Climate project, integrating innovation throughout the entire project cycle.<sup>11</sup> With the support from the Innovation Facility, the project team was encouraged to engage in a process of testing and learning as well as to embrace failure as a necessary step for success. Through a continuous process of empathizing, ideating, prototyping and testing, the team was able to gather learnings that are crucial for pivoting and redefining the direction the initiative must take for further scale up. The pilot project was established as a first phase of a larger initiative that aims to leverage the potential of IoT technologies and applications for climate adaptation.

Using an innovation approach facilitated the pivoting at different instances. For instance, a very interesting outcome of this pilot phase has been the development of an Application Programming Interface (API) prototype for Meteo by one of the teams that took part in the Design-a-thon. While the teams were meant to work on developing applications for delivering climate information, it became apparent in the conversations held with Meteo that there was a need for an API if the developers were to access the data for developing useful applications. Teams wanting to build applications on top of weather predictions and real-time information were unable to do so because of some technical limitations. Seeing these shortcomings, one team decided to pivot from predictive analysis to the development of an API. An API would allow users to register automatically and continually receive real-time data. Rather than working only with historical data, users of the API would be able to utilize current conditions and see the most current predictions. The API would also integrate Meteo's various sources of weather information, which are stored in different databases. Moreover, the API would allow Meteo's predictions to be stored in an organized, structured way, providing an advantage for application developers wanting to make use of this data as well as Meteo officials interested in the accuracy of their results. The API is sure to unlock a range of real-time and predictive applications, and facilitate the improvement of Meteo's own predictive models. It was through this approach of testing and learning that teams were able to get a clear understanding of Meteo's needs as well as to pivot when there was a need to do so.

<sup>&</sup>lt;sup>11</sup> The "Project Cycle Hackers Toolkit" was useful for integrating innovation in the project design and implementation and wrap up.



Figure 1. Innovation approach used for the IoT for Climate project

The pilot project focused on a strong **user-centered approach**. Moving away from the notion of "beneficiary", the project focused on understanding the needs of the "users" it was trying to serve. By switching to the notion of "user", UNDP envisioned the active engagement and participation of the population it wished to support, in this case smallholder farmers. In order to get a good understanding of the user profiles and needs, a series of interviews were conducted and exercises such as "Develop a persona" were carried out. Discussions with key stakeholders were held to further understand user insights and needs. Results about the engagement with stakeholders and users can be further explored in the section "User profiles and needs". Major findings included the users' need for climate data specific to their village, considering the challenge of microclimates at the district and sector levels. During the Design-a-thon for Climate, participants were also encouraged to first focus on understanding the user profiles and needs in order to develop user-centered applications. On the first day of the Design-a-thon workshop participants worked on developing a persona within their teams. On the following day they were able to do a site visit to interview farmers and sector agronomists in order to empathize with their users and get better insights.

However objective one may try to be, projects are based on many assumptions at the problem statement level. UNDP made sure to reflect on the initial problem statement by **testing assumptions**. Through the "test your assumptions" exercise, the UNDP team revealed assumptions, crafted hypothesis and came up with ways to test them against reality. Assumptions were tested by talking to users, technical experts and stakeholders. Based on these learnings, the problem was reviewed before moving to the implementation of the pilot project.

The project also used a **collective innovation approach** by engaging a wide range of stakeholders. A major objective of the pilot project is to catalyze a technology innovation system from within the country. UNDP therefore made an effort to engage various stakeholders from the beginning and designed the project in a collective manner, while conducting many field visits to listen to the voice of the potential users of the planned service and allowing pivoting of the project direction several times. This 'collective innovation' approach was taken for site selection, sensor data selection and information dissemination.

The project further used a lean startup approach, by which ideas were prototyped and tested continuously. From selecting the site all the way to developing the applications for the end users, there was always a process of testing and learning. UNDP did site visits and talked to a wide range of stakeholders before selecting the sites for the pilot project. Prior to setting up the IoT sensors, the project team first tried out the entire value chain; assembling the sensors, setting them up, and sending data to the server. For instance, given that the boxes are open source, TCT graduates were able to prototype and test the sensor boxes until they would see what works better. Instead of hiring an expert, UNDP wanted vocational school graduates and Meteo staff to gain ownership of the technologies and to go through this testing and learning process. The University of Tokyo actively chose not to do transfer of knowledge through a conventional training, but through experiential learning by actually taking the graduates and stakeholders to the project site to collectively think and do sensor experiments. Throughout this entire process, the project team faced many challenges, from which they were able to learn and build for a greater success. Lastly, Internet of Things applications were developed also through a lean startup approach. During the Design-a-thon for Climate, participants were encouraged to first build rough prototypes that could be tested with the end-users to gather early feedback. They later worked on developing a Minimum Viable Product to present during the partnership workshop. This MVP is expected to continue being tested to gather more feedback that can be incorporated in the development of new versions of the technologies until a final application is developed.

Projects at the initiation or pilot stage are encouraged to prototype, failing quickly to learn and pivot at the earliest possible. The pilot project IoT for Climate did a lot of **prototyping and pivoting** during this first phase. Based on the learnings from this first experience, the project can be furthered scaled up to the national level.

**Scaling and making solutions sustainable** - As part of the pilot project, partnership workshops have been designed to bring together key stakeholders and discuss how to scale the IoT for Climate Initiative. This report serves to document strategies for scale up as well as to reflect on the process of the pilot project so far and explore ways to make the project sustainable. Suggestions for scaling up are captured in the section "Options for scaling". Furthermore, lessons learned from the pilot project are described in the last section.

## **1.3 Overview of the IoT for Climate pilot project**

Considering the pressing challenge of climate-related risks in Rwanda and in the region as well as the need for more accurate climate and weather data and information, Meteo Rwanda and UNDP piloted the project "Internet of Things (IoT) for Climate Change" (or IoT for Climate). The pilot project consisted of two phases. Phase One was implemented in collaboration with University of Tokyo and with seed funding from UNDP Innovation Facility. This Phase focused on IoT for Climate Change and Water Management to test a new real-time microclimate data collection methodology using IoT technology in three small-scale sites. Phase Two was implemented in collaboration with RISA and funding from Noreps and focused on IoT for Climate Early Warning and Humanitarian Response.

UNDP understands that for innovation to happen there needs to be a big investment in learning, which is why the pilot project focused on testing different aspects throughout the entire value chain, including the collection, assimilation, distribution and usage of climate data. Through this process the project team was able to gain a clear understanding of the needs of the smallholder farmers, vulnerable populations, meteorological agency and other key stakeholders, as well as to capture key learnings that would set the direction for further scale up of this initiative. Based on these learnings, the initiative is better positioned to use new IoT technologies and applications to reduce the vulnerability to climate change. The direction and potential pathways for moving forward can be found in **Chapter 3.2**.

#### 1.3.1 Objectives and scope

Acknowledging the emerging IoT concept, the initiative aims to develop new technologies and applications that can sustainably address existing and future emerging climate issues through "real time" environmental data collection, analysis, dissemination and applications. The project also aims to transfer technology to strengthen the capacity from upstream sensor engineering skills to downstream data application on using IoT for climate and environmental issues, creating space for new business and job opportunities in Rwanda.

The initiative piloted the IoT concept by setting up sensors and open-source data relay boxes in Kayonza District in the Eastern Province of Rwanda where drought and water shortage are persisting issues. Data such as soil moisture, temperature and humidity was collected real time, and applications were developed for analyzing and disseminating the climate data in an effective and understandable way through close consultation with potential users such as the vulnerable population and DRR or agricultural planning agencies. While the pilot project focused on weather related issues, such as measurement of soil temperature, and humidity, the technology could potentially be applied to other environmental data collection including forestry, biodiversity and pollution. More on the potential of this initiative can be found under **section 2.4**.

This initiative is further linked to the government's efforts to expand Rwanda's commitment to the "Internet of Things" (IoT). It is likewise hoped that the technologies and applications developed under this initiative in Rwanda could be scaled geographically to other Sub-Saharan countries.

#### Outcome 1. Vulnerability to climate change mitigated through real-time micro data provision

Real-time data collection and dissemination will support decision making at the population level (farmers, direct early warning) and the policy planning level (agricultural planning, Disaster Risk Management) to reduce vulnerability to climate change related issues.

- Output 1.1 Integrated and efficient data-based water / soil moisture pilot data collection system established in climate vulnerable area
- Output 1.2 Network of sensors, data collection method and applications tested and established, specifically for the needs of vulnerable populations

#### Outcome 2. New jobs created from upstream to downstream of the IoT industry

Technology transfer and capacity development are expected to take place from upstream assembly to downstream data application through 'learning by doing' and training opportunities. The new IoT industry will create new jobs from within the country and for serving other Sub-Saharan countries.

- Output 2.1 Capacity built from upstream engineering to downstream data application (research, GIS data analysis, application development to sensor production)
- Output 2.2 Opportunities and challenges identified for scale up of the idea of using IoT for climate change adaptation

#### 1.3.2 Project activities

The project activities were split in Phase One (August 2017 – March 2018) and Phase Two (April – July 2018). For these piloting phases, the project focused on Kayonza District. Kayonza is one of the districts identified as most vulnerable to drought in the National Risk Atlas (MIDIMAR), with 26% of the district land exposed to severe drought and agriculture at high risk. Part of Akagera National Park lies in the district, and it is within the so-called "Cattle Corridor", an extremely dry area stretching from south to north of the eastern side of the Province. Major challenges related to climate issues identified in the District Plan (2013-2017) are; agriculture based on weather, large number of vulnerable groups (41634 people / 11196 households); limited access to socio-economic infrastructure (eg. electricity) and environment issues such as drought and soil erosion. Lack of meteorological stations, low rainfall and lack of capacity for disaster risk management have also been identified.

#### Phase One

Phase One of the project focused on testing sensors for collecting better climate data as well as prototyping and testing applications to disseminate information to smallholder farmers. The project tested open source Internet of Things (IoT) technology since August 2017. The technology had already been developed by Next Generation Space System Technology Research Association (NESTRA) through open innovation applications in Japan. Through initial consultation with national key stakeholders such as MIDIMAR, RAB, RWFA, MINALOC, and with technical consultation within Meteo and the professors of the University of Tokyo, Kayonza District was selected as project site for the implementation of IoT sensors set-up. After a scoping field visit to potential areas, consultation with the district officials, and also through discussion with stakeholders, Murundi, Ndego and

Rwinkwavu Sectors were identified as sites which are facing especially severe drought risk and water deficit.

12 IoT sensors were set up in Murundi, Ndego and Rwinkwavu sectors. To achieve this, a training on how to assemble sensor data relay boxes as well as stakeholder workshops and field visits were conducted. University of Tokyo (UoT) staff provided training to Tumba College of Technology (TCT) graduates on the concept of IoT, assembly of the data relay box and software instalment. Following the training, a workshop with key stakeholders was held to gain a better understanding on IoT and meteorological application, do a site visit and discuss actual places for setting up sensors as well as discuss safety measures. This workshop was followed by a site visit to the three sectors.



Early this year and after bringing sensors from Japan, the University of Tokyo staff, UNDP representatives, Meteo technical staff and Tumba College of Technology (TCT) graduates travelled to TCT to reassemble the sensor boxes as well as discuss the problems the sensor boxes could potentially face and find solutions. The 12 sensors were set up in Murundi, Ndego and Rwinkwavu, and sector officers received instructions on how to take care of the sensors. The sensors were collecting data every 15 minutes.

After the sensors were set up and data was being collected in the server, UNDP with Meteo Rwanda and the University of Tokyo conducted a Design-a-thon to convert this real time *data* into usable and accessible *information* applications through a collective designing process, bringing together national and local stakeholders, young programmers and technology experts.

The Design-a-thon for Climate lasted three days. 18 teams made of 66 participants were introduced to the design challenges and were guided throughout the entire Design Thinking process to come up with ideas and prototypes of climate information applications that can accelerate effective planning and decision-making in agricultural planning.

Participants had the opportunity to do a field visit to Rwinkwavu Sector to see how the sensors work and talk to sector agronomists and smallholder farmers. They were able to get a better understanding of their users' needs and ask for feedback on the prototypes of their applications. After pitching their proposed applications in front of a jury, six teams were selected to go to the next stage and work on developing a minimum viable product (MVP) for 20 days. The participants' understanding of the issues faced by METEO Rwanda, RAB agronomists, and smallholder farmers was informed by numerous meetings and field visits.



In summary, the teams worked on the following solutions:

- SMS and USSD application to send climate information to farmers
- Android applications for Sector Agronomists to have better access to data and to communicate directly with farmers
- Prediction of particular indicators (soil moisture) relevant to RAB agronomists who use these to advise farmers when to plan their crops
- API to access climate data from Meteo Rwanda

The final application prototypes were then presented at the Partnership Workshop. Applications were judged by how well they met the stakeholder needs and the quality of the code and software architecture. The winning prototype was:

#### Kubero - 1st place

Kubero proposed building two applications: one Android app to be used by RAB (agronomists) and a USSD application primarily for the farmers to query weather data. The android application would help RAB add value to the predicted data by recommending farmers what to do based on the weather data as well as allowing agronomists to communicate directly with the farmers through SMS. This application also includes a feature to help Meteo volunteers submit weather data to Meteo in a digital and ready to use format. The USSD application instead would be used by farmers to receive weather information and recommendations from RAB as well as to provide feedback to Meteo on the accuracy of the predictions, helping improve Meteo's prediction models.

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Figure 2: Screenshots of Kubero application

A description of other winning solutions can be found in **Annex 3**.

#### Phase Two

This second phase of the project focused on deepening the learnings from Phase One. Winning solutions of Phase I were further developed and tested. The farmers' application was tested with agronomists and farmers, and the feedback collected was incorporated. The application aims to disseminate information with suggestions from agronomists to farmers for better agricultural planning. The application is ready to be piloted before a mass rollout. The volunteer observer application was also further developed and tested and is ready for implementation. This application will allow volunteer observers to digitize the recording of data at Meteo Rwanda manual stations. The other solution, the API, was further developed and installed on a server in Meteo Rwanda Headquarters, with a publicly facing IP address. A training session was conducted for Meteo staff to know how to maintain the application, ensuring that the server is running and connected, and that it has all the right permissions to access to Meteo's database. The API will improve access to Meteo Rwanda data and allow the development of new climate information applications/products.

As part of this second phase, a roundtable discussion was held with stakeholders, including Meteo Rwanda, MIDIMAR, RAB and WFP, to identify key challenges regarding climate information for Early Warning in the country. The discussions allowed for a clear understanding of the flow of climate information and helped identify and document the gaps in setting up an early warning system. The gaps identified can be broadly categorized in the following (more details on the gaps and needs identified can be found in section 2.2):

- **Collection of climate data:** Climate data is critical for disaster risk management, early warning and rapid response to disaster. However, there are challenges associated to the collection of localized data in a timely and accurate manner.
- Integration of climate data: Data collected by Meteo Rwanda needs to be integrated with other relevant data (such as MIDIMAR database of disasters and disaster risk profiles) to improve the capacities to prepare for disasters.

• **Dissemination of climate data:** Finally, there are challenges in the flow of communication between agencies involved in disaster preparedness, including Meteo Rwanda and MIDIMAR, and between agencies and the end-users. There is a need for mechanisms and tools to improve the dissemination of weather information and Early Warnings to local communities in order to reduce their vulnerability to disasters.

Having identified key challenges in the Roundtable Discussion, Meteo Rwanda and UNDP organized the five days Hackathon for Climate Early Warning in Kayonza District, bringing together 10 teams made up of 33 participants. The teams were introduced to design thinking and then focused on prototyping and testing solutions to the challenges presented. Throughout the five days, they talked to government stakeholders to gain more insights into the gaps and needs as well as received technical guidance from various mentors. The Hackathon emphasized the relevance of collaborating to co-create relevant solutions as opposed to competing, and created spaces for participants to share their work and ideas.



On the side of the hackathon event, there were a series of trainings on the basics of IoT technologies, IoT weather stations and IoT for Early Warning. The trainings were attended by key project stakeholders such as Meteo Rwanda, MIDIMAR and RAB staff, and Tumba College of Technology graduates. Additionally, they were optional for Hackathon participants interested in deepening their knowledge in IoT.



As part of the IoT training and in the framework of the hackathon, an analysis was also conducted on the hardware and data of the sensors installed during Phase One of the project. The sensor analysis led to a few key findings related to the durability and accuracy of the IoT sensors. Firstly, the data shows that the devices from Rwinkwavu were only transmitting information for about one month. This is attributable to a power failure caused by either the solar panel breaking off or becoming so dirty that is ceases to function. Within the month the IoT sensors were transmitting, there is a slight difference between the IoT data and Meteo's own readings. Comparing temperature, it is clear that while most of the time the IoT sensors matches Meteo Rwanda, they consistently reach higher peaks than the WMO standardized Meteo readings. This could be attributed to a need for calibration or improper sensor placement; at Rwinkwavu we discovered that the temperature sensor had been placed inside a metal pole. While quality sensors and regular calibration are key, it is clear that the IoT sensor project cannot function without the sector-level stations' help in maintenance and diagnostics.

At the end of the Hackathon event, participating teams pitched their solutions to a jury. The grand winners included:

#### STES

Sensors to collect soil moisture data placed at different depth levels and a dashboard to monitor if the sensors are working or not. Their solution proposes the use of radio mesh network to send data of sensors to base stations. The benefits of the system are that it is low-cost, it can work in remote areas, collects data automatically, is easy to maintain and can be calibrated through comparison which is cost effective. The collection of soil moisture data can help predict landslides.



Figure 3: Image of soil moisture sensor and diagram of mesh network

#### EcoDev

A solution that aims to improve flash flood early warning system using Machine Learning techniques, with the option to apply methods to other natural disaster later on. A web platform will use a machine learning algorithm to help MIDIMAR to quickly identify at risk areas, visualize the areas on the map and communicate the information to concerned officers.



Figure 4: Diagram of EcoDev solution

#### **Binary Earth**

B.E AWARE platform visualizes Meteo weather alerts and MIDIMAR disaster information together in context. Using Meteo weather alerts and GIS, the platform produces a live map of disaster areas. The

platform further produces dynamic historical disasters maps to help in preparedness. It also incorporates channels to help MIDIMAR automatically communicate to officials and end users.



Figure 5: Screenshot of Binary Earth solution

A description of other winning solutions can be found in Annex 3.

In summary, teams worked on the following solutions, which can be scaled up in Phase Three of this project:

- Low-cost sensors to collect soil moisture data and a dashboard to monitor sensors data
- Platform using machine learning algorithm to help MIDIMAR to quickly identify at risk areas, visualize the areas on the map and communicate the information to concerned officers
- Platform to visualize disaster risk areas by contextualizing Meteo weather forecasts with MIDIMAR disaster risk profiles
- Platform to automate the flow of communication between Meteo and MIDIMAR, and between MIDIMAR and the vulnerable population (end users)
- Android, SMS and USSD applications as well as sirens to disseminate early warning information to the population

At the end of Phase Two, a partnership workshop was conducted to review the project so far and discuss ideas for scale up of the IoT for Climate project after the pilot phase. The workshop lasted half day, where the overview of the project and key findings were presented. Furthermore, stakeholders discussed possible ways of scaling up the project. The discussion outcomes can be found in **chapter 3.2**.

#### **1.3.3** Key achievements of the IoT for Climate pilot project

#### General

- Key stakeholders, including Meteo Rwanda, RAB, RWFA, MIDIMAR, REMA, Kayonza District officials and Murundi, Ndego and Rwinkwavu sectors, were engaged in the design and implementation of the pilot project and are supportive of the initiative and its future scale up.
- A strong understanding of the needs of vulnerable populations and key stakeholders was attained through extensive stakeholder engagement, user interviews and field visits to Murundi, Ndego and Rwinkwavu Sectors in Kayonza District.

#### Phase One

- 12 IoT sensors were assembled, set up and maintained in Murundi, Ndego and Rwinkwavu sectors in Kayonza District to collect real-time data such as soil moisture, temperature and humidity, based on stakeholder consultation and needs assessment. The process involved trainings, stakeholder workshops and field visits.
- A data collection server was established: data from IoT sensors was collected and sent to the WiredIn server using WiFi.
- Capacity was built through "learning by doing" University of Tokyo and Meteo staff trained Tumba College of Technology graduates on IoT sensors assembly, set up and maintenance.
- Sector officers acquired knowledge on the concept of IoT as well as the function and maintenance of IoT sensors.
- 66 young tech experts, programmers and scientists (52 men and 14 women) came together to design IoT applications for climate change adaptation during the Design-a-thon for Climate. The participants acquired knowledge and skills on Design Thinking and worked in teams to prototype applications relevant to the needs of smallholder farmers.
- As an outcome of the Design-a-thon, 6 teams worked on further developing their prototypes:
  - 5 climate information application prototypes were developed for analyzing and disseminating climate data in an effective and understandable way. The first winning solution included one android app to be used by RAB to provide recommendations to farmers based on weather data as well as a USSD app to be used by farmers to receive weather information and recommendations from RAB and to provide feedback to Meteo on the accuracy of the predictions, helping improve Meteo's prediction models.
  - An API prototype was developed to interface with all applications that need data from Meteo. The API prototype received the Innovation Award for wanting to facilitate the process of acquiring data from Meteo, unlocking a range of real-time and predictive applications, and helping improve Meteo's own predictive models.
  - In addition to the main solutions proposed, a number of teams took up the task of helping Meteo verify the accuracy of the recordings of the volunteer observers at the manual stations. Following Meteo's request, the teams integrated features to facilitate volunteer observer recordings with geo-location mechanisms to verify that the recording was taken in the correct place.

#### Phase 2

- Data and hardware analysis of sensors revealed technological challenges and informed way forward for using IoT sensors. While quality sensors and regular calibration are key, it is clear that the IoT sensor project cannot function without the sector-level stations' help in maintenance and diagnostics.
- Gaps along the climate information for early warning were clearly identified and documented and 10 solutions were prototyped through the Hackathon for Climate Early Warning.
- 38 participants from stakeholder institutions were trained during the Hackathon side event sessions on IoT technologies, IoT weather stations and IoT for Early Warning.
- 33 young programmers and developers (4 women and 29 men) came together to prototype and test solutions for Climate Early Warning. The participants acquired knowledge on Design Thinking, gain insights to the problematics by talking to government stakeholders and received technical mentorship for their prototyping.
- Teams came up with the following pototype solutions, which have the potential of being scaled up in the next project phase:
  - Low-cost sensors to collect soil moisture data and a dashboard to monitor sensors data
  - Platform using machine learning algorithm to help MIDIMAR to quickly identify at risk areas, visualize the areas on the map and communicate the information to concerned officers
  - Platform to visualize disaster risk areas by contextualizing Meteo weather forecasts with MIDIMAR disaster risk profiles
  - Platform to automate the flow of communication between Meteo and MIDIMAR, and between MIDIMAR and the vulnerable population (end users)
  - Android, SMS and USSD applications as well as sirens to disseminate early warning information to the population
- Winning prototypes of Phase I were further developed and tested.
  - Application to disseminate information with suggestions to farmers was developed and tested, and is ready to be piloted
  - API was developed and installed on a server in Meteo Rwanda, which will improve access to climate data and allow the development of new climate information applications
  - Volunteer observers application was developed and is ready for roll out, which will help digitize the recording of data at the manual weather stations
- A partnership workshop was conducted and strategies for scale up were identified. Key strategies can be found in **chapter 3.2**.
- The present report was written to document the experience of the pilot project and identify challenges, opportunities and strategies for scale up of IoT for climate change adaptation.

# **Chapter 2: Key findings**

# 2.1 IoT for Climate Value Chain



#### Figure 6. Objectives and pathways for IoT for Climate

In order to improve the climate information flow for better climate adaptation, there is a need to work along the entire value chain, from data collection to data analysis, dissemination and usage.

Improving the **collection of data** requires strengthening Meteo Rwanda's data network, which can be done through multiple ways:

- 1. Strengthening the existing network of weather stations by expanding the coverage of automatic weather stations as well as through the digitization of the data that is collected manually.
- 2. Using new IoT technologies, such as soil moisture sensors and small scale WMO compliant weather stations

3. Opening up to the public by partnering with private sector, academia and civil society and/or by inviting anonymous IoT sensors to supplement and calibrate to Meteo's data.

Improving the **assimilation of climate data** requires improving Meteo's weather and hazard modelling, which can be accomplished by:

- 1. Improving basic capacity of Meteo Rwanda through the development of capacities of the forecasting staff and better modelling software
- 2. Improve modelling based on feedback received from end users on the accuracy of the forecasts and by storing past forecasts and actual weather efficiently
- 3. Integrating Meteo Rwanda data with other relevant climate and weather related data from institutions such as RWFA, RAB and MIDIMAR

Improving access to and dissemination of climate data can be done by:

- 1. Improving the dissemination of weather information and alerts directly from Meteo Rwanda
- 2. Improving the dissemination of climate information through coordination with other institutions such as
  - a. MINAGRI and RAB to send out information to farmers on daily and emergency alerts
  - b. MIDIMAR to communicate and create Early Warnings
- 3. Increasing the accessibility and openness of Meteo Rwanda climate data, for instance, through an API

**Using climate information** for better agricultural planning, early warning and DRM, water management, and/or environmental monitoring, among others, requires

- 1. Improving climate information products for different purposes
- 2. Raising the awareness and skills to fully use new climate information
- 3. Allowing other climate information usage by broad actors outside public institutions through the API access by permission and open data policy

## 2.2 User profiles and needs of climate information in Rwanda

Understanding the users is essential for designing solutions that effectively meet their needs and that will be adopted with greater success. IoT for Climate has the potential of serving vulnerable populations in Rwanda, including smallholder farmers and population vulnerable to climate related risks such as drought and floods.

#### User Profile of Phase One: Farmers in need of weather forecasts

The first phase of this pilot project identified as users the farmers in rural areas who need to utilize daily weather forecasts better in order to secure harvest and better prepared to climate change adaptation. The population of Rwanda is still largely rural with 83 percent living in rural areas.<sup>12</sup> Agriculture occupies about 80 percent of the labour force and contributes around one third of the overall GDP. The majority are smallholder farmers with an average land size of 0.59 hectares. Smallholder farmers are largely dependent on rainfall due to the lack of irrigation systems in place, and are therefore vulnerable to climate and weather-related risks, including prolonged droughts, particularly in the East and Southeast provinces, as well as erratic rains, floods, hailstorms and mudslides, mostly in the Northern and Western provinces.<sup>13</sup> Smallholder farmers lack the knowledge, skills and adequate infrastructure to cope with such weather and climate hazards, experiencing severe losses in their production and household income. Drought is one of the major hazards affecting smallholder farmers in Rwanda.

Based on a user-centered approach, the pilot project IoT for Climate did an assessment of smallholder farmers and their needs through user interviews, field visits and by engaging with stakeholders and experts who provided more insights into the problem. Below is an understanding of the user needs, profiles and context that was acquired throughout various instances in the design and implementation phases. This serves as an initial baseline study, but for future scale up to the national level, it is necessary to continue doing thorough assessments of the needs by sector and adapting the IoT solutions to the sector needs.

The pilot project focused on Kayonza, one of the districts identified as most vulnerable to drought in the National Risk Atlas (MIDIMAR). Part of Akagera National Park lies in the district, and it is within the so-called "Cattle Corridor", an extremely dry area stretching from south to north of the eastern side of the Province. Major challenges related to climate issues identified are; agriculture based on weather, large number of vulnerable groups (41,634 people / 11,196 households); limited access to socio-economic infrastructure and environment issues such as drought and soil erosion. Lack of meteorological stations, low rainfall and lack of capacity for disaster risk management have also been identified.

From the initial consultations and interviews with users and stakeholders, what stood out as a clear finding was the need for more timely and accurate information specific to the local (cell) level as well

<sup>&</sup>lt;sup>12</sup> Government of Rwanda. Science & Technology in Rwanda, p. 5

<sup>&</sup>lt;sup>13</sup> World Bank and CIAT (2015). Climate-Smart Agriculture in Rwanda. CSA Country Profiles for Africa, Asia, and Latin America and the Caribbean Series. Washington D.C.: The world Bank Group.
as the need for information that is understandable to the users. Users indicated that simply knowing the temperature does not help them, but that information needs to be packaged and presented in a certain way for them to be able to make better decisions. Users and stakeholders further highlighted the issue of microclimates in the district, by which there are significant weather changes between very short distances. Whereas one cell can be receiving rainfall, the neighbouring cell can be without any rain.

Stakeholders and users of the information expressed the need for more targeted and speedy information. Presently, climate related data is collected and analyzed by Meteo Rwanda under the Ministry of Environment. Meteo's observational network platform is mostly composed of manual weather stations, meaning that data collection is done mostly manual, with one volunteer observer per station writing down the record for the day and sending the data as a monthly report by phone or paper form. Based on the information Meteo receives, it can produce a 5-day forecast as well as a monthly and seasonal forecast. District agronomists can access this information, and later communicate to sector agronomists by channels such as whatsapp groups. Sector agronomists later communicate such information to farming cooperative leaders, who at the same time pass the information to the rest of the farmers. Some farmers also receive such information directly from Meteo through the radio and SMS services. The process is, however, slow and leaves much room for human error. Additionally, traditional weather stations are sparse and are not able to collect micro-level data; hence leading to forecasts that are general to the district and not to the cell level.



Figure 7. Process of collection and dissemination of climate data

In the framework of workshops and informal consultations, stakeholders and users discussed the type of information that is needed as well as challenges for community engagement and recommendations for information dissemination. Considering that the main challenge in Kayonza District is drought, climate information that is needed includes rainfall information, temperature

information, wind information, soil moisture, solar radiation, crop and livestock information, and agricultural practices information.

RAB, for instance, mentioned the importance of getting soil moisture data. Soil moisture and soil temperature influence seed germination, plant growth, uptake of nutrients, soil respiration, soil evaporation, and intensity of physical, chemical, and microbiological processes. Soil moisture data can often be more important than rainfall data in agriculture since poor yields are related to an insufficiency of soil moisture rather than to an insufficiency of rainfall. According to RAB, there is a need for data on the variability of soil temperature, moisture and solar radiation to support decision making in the agricultural sector in Rwanda. This data can serve for yield forecasting, climate risk assessment, suitability maps, irrigation and fertilization practices and advisory services.

During the stakeholder workshops, recommendations for information dissemination included to equip each cell with electricity (REG and solar panel); use available BTs; collaborate with all relevant stakeholders; collaborate with existing dissemination channels (e.g. Twigire muhinzi agricultural extension model); use USSD codes/ message notifications; and construct a-two way communication system for instantaneous feedback, by which farmers can report back on the precision of the forecast.

Challenges	Opportunities
Low smartphone usage	Settlements     Cooperatives
Level of education / knowledge	<ul> <li>Network coverage</li> <li>Community works/ regular meetings</li> </ul>
Infrastructure (internet, electricity, cellular connectivity)	<ul> <li>Expanding coverage of cellular network due to various network operators</li> <li>Companies who can distribute solar panels</li> <li>Affordable internet</li> </ul>
Information delivery (type of information that is being delivered to the community)	<ul> <li>Settlements</li> <li>Cooperatives</li> <li>Community works/regular meetings</li> </ul>
Culture (analogue prediction)	<ul> <li>Emerging level of education</li> <li>Government programs (Smart classrooms, 12 YBE)</li> </ul>

Participants also discussed challenges and opportunities for community engagement, which are outlined below:

Based on in-depth interviews to farmers and agronomists during field visits to Murundi, Ndego and Rwinkwavu Sectors, general and site specific sector needs and issues were identified as below. For the interviews, tools such as "Develop a persona" from the UNDP's Project Cycle Hackers Kit were used. This tool helped to map out the key characteristics of the users the project was trying to work with.

Develop a persona     A persona helps you to map out the key characte     Norking for and share it with others. You may use     segments or groups of people.	ristics of the people you are different personas for different			2c	
Name Rashind Portrait Please add a picture of draw a portrait Where there is will, there is always a way					
Segment Occupation Age 60 Home town Marital status Family/Friends	Motivations What drives this persona? Working hard, feeding/production of agricultural products, working step by step	Goals What are the goals that this persona tries to achieve? Modern farming, water harvesting		Frustrations What frustrates this persona? adverse weather conditions	
Interests/Hobbies Reading Short bio Short bio Enabless What enables this persona to achieve his/her goals? Government subsidies, technico advise			Barriers What obstructs this personal from achieving his/her objectives? limitation of land, (small land) little knowledge, good cattle breed that can adapt to climatic zone		

### Figure 8. "Develop a persona" tool from UNDP Project Cycle Hackers Kit

Some general issues to all three sectors included the lack of trust for forecast information provided by Meteo Rwanda due to its generality. The information provided is not specific to the cell level but it is general to the sector level. Furthermore, the information is not specific to their sector of agricultural activities.

"Climate change is a big challenge for us because we sometimes sow seeds but it changes. Some days they announce that on a given day it will rain and it doesn't rain like they predicted. Nowadays it is the most confusing... At Mucucu [the cell next door] they told us it has rained but it didn't rain here... Not being able to get correct information we end up sowing contrary to the forecast and loose crops." (Esther - Farmer of Murundi Sector)

Also, users explained that the crop insurance failed due to inaccuracy of satellite data. Often satellite data would show there had been rain while in reality there had been no rain on the ground, meaning the insurance company would not pay and farmers would be left with frustration. Smallholder farmers are very much dependent on agriculture, with other livelihood opportunities being limited. Another issue is that farmers lack information on crop selection and planting dates. Lastly, the majority of farmers do not have smartphones.

"Some people had insured their crops and the weather information [the insurance company] relied on satellite which was more regional than local. At the end of the day, the crops failed and the insurance wouldn't pay." (Rashid - Farmer of Murundi Sector)

"If they could give us a package of everything on weather it would be good. So you get soil moisture, you get wind, you get temperature atmosphere. And it would be much better if this information went through Meteo Rwanda or some other organization that could interpret it and give it to the farmer when it is understandable to them." (Rashid - Farmer of Murundi Sector)

Some needs across the three different sectors included the following: 1) Given the microclimate challenge in the different sectors where climate variates strongly within short distances, farmers need more accurate data that reflects what is happening in their specific cell. 2) Users also pointed to the need for information to be packaged and not be delivered as pure data, but together with some guidance and advice. 3) Users also expressed the need for building capacity of farmers on how to interpret and use climate data for effective decision-making and better planning in farming.

Murundi Sector faces severe drought, although climate differs drastically within the sector. The sector has faced several severe droughts in the past years as well as strong winds from non-traditional directions. In particular, two out of four cells are more exposed to drought. Some specific needs that were heard in this sector include: farmers have mini irrigation systems, but do not know when to start using; the wind direction information and alert for strong wind a few hours in advance will avail farmers to prepare; there is a need for more solar panels if sensors want to be installed (while some farmers have solar panels, these have limited capacity to hold an additional device).

Rwinkwavu Sector was identified by local stakeholders as another dry area with the same climatic "band". Issues faced in this sector include drought in two out of the four cells; only one harvest per year and distrust to the meteorological information and forecasts provided due to their generality. Specific needs that were raised included the need for capacity building in order to utilize well climate information as well as the need for water tanks or mini dams to store rainwater.

Ndego Sector was identified as a very relevant site for the pilot project as it did not experience any rain the year before. Among the issues faced were dryness in all of the sector cells, prolonged drought the year before and irrigation projects that are not reaching the population as a whole. Other issues included the limited connection to the grid, which means smallholder farmers cannot diversify their livelihoods and the unpredictable winds that are destroying houses and crops. Specific needs raised by the population included the need for capacities to build climate resilient houses as well as the need to diversity livelihoods and water tanks that function well.

#### User Profile of Phase Two: Population vulnerable to disasters

Phase two of the project identified as users the broader population vulnerable to disasters including flood, landslide and drought and who are in need of early warning to evacuate or prepare. Through consultation with key stakeholders such as Meteo Rwanda and MIDIMAR, the project was able to visualize the flow of information and understand the clear gaps in setting up an early warning system.



Figure 9. Flow of climate information for Early Warning

Meteo Rwanda and the Ministry of Disaster Management and Refugee Affairs (MIDIMAR) both play an important role in the early-warning process. Meteo is responsible for collecting and sharing weather information such as daily, weekly, and seasonal forecasts, as well as urgent weather events. Meteo is responsible for passing urgent weather information to MIDIMAR, which is then responsible for issuing alerts to local communities. MIDIMAR accesses urgent weather information from Meteo through different channels such as whatsapp groups, emails and through the website. This information is then communicated to MIDIMAR district officials, who then pass the information to sector and cell level officials who can alert the population.

Climate data is critical for disaster risk management, early warning and rapid response to disaster. However, localized data is difficult to collect. As mentioned above, climate related data is collected and analyzed by Meteo Rwanda. There is a need to improve the collection of data in a timely and accurate manner. Through roundtable discussions with key stakeholders in phase two, main challenges identified in deploying IoT sensors or expanding the network of weather stations include cost, connectivity, electricity, security and WMO compliance.

Besides the data being collected by Meteo Rwanda, MIDIMAR also maintains disaster risk profiles as part of the National Risk Atlas<sup>14</sup>, which describe the risk of droughts, floods, landslides, earthquakes and windstorms throughout the country. The rountable discussions with Meteo Rwanda, MIDIMAR and other key stakeholders served to understand the need for integrating and contextualizing data being collected both by Meteo Rwanda and MIDIMAR.

The ability to integrate Meteo weather information with MIDIMAR's database of disasters and disaster risk profiles is critically important for building MIDIMAR's capacity to effectively issue weather-related alerts. Currently there is no way to dynamically update the atlas of disaster-prone areas based on local observations, nor has the database of previous disasters been used to build a formal representation of risky areas. Furthermore, the ability to compare and visualize Meteo weather information with MIDIMAR's database of disasters and disaster risk profiles is critically important for building MIDIMAR's disaster analysis capabilities. Currently there is no way to effectively layer Meteo alerts with MIDIMAR's disaster risk profiles. There is also no way for MIDIMAR staff to quickly identify which areas are at risk, given a new weather alert.

Finally, stakeholders discussed the need for improving the flow of communication between Meteo Rwanda and MIDIMAR and the dissemination of weather information and Early Warnings to local communities in order to reduce their vulnerability to disasters.

In order for the population to be better prepared and respond to climate related hazards, there is a need to have mechanisms and tools in place to share accurate weather information in a timely manner. Presently, MIDIMAR needs to retrieve climate information from Meteo to then share with MIDIMAR district officials, who then share with sector and cell level officials. This process can take a long time, leaving less time for local communities to respond.

Sending out early warnings to the population require the strong coordination between Meteo and MIDIMAR. There is a need for an automatic system to share information between Meteo and MIDIMAR and from MIDIMAR to district and sector level agents, in order to increase accountability and better coordinate response in the event of an impending disaster.

Furthermore, there is a need for good channels of communication between governmental agencies involved in Early Warning and local communities, especially in the event of an impending disaster. There is a need to clearly display or announce this urgent information to local citizens in a format that is widely accessible.

<sup>&</sup>lt;sup>14</sup> <u>http://midimar.gov.rw/uploads/tx\_download/National\_Risk\_Atlas\_of\_Rwanda\_electronic\_version.pdf</u>

## 2.3 Stakeholder mapping around climate information in Rwanda

Engagement of key stakeholders is crucial to ensure the success and sustainability of the IoT for Climate project. A wide range of stakeholders were involved during the pilot project to ensure that the technologies and applications are relevant and meet the needs of the users.

These stakeholders contributed to the pilot project by sharing expertise, providing technical advice and data, and sharing insights into the community needs. UNDP and Meteo Rwanda were the lead organizations implementing this pilot project, with the support University of Tokyo, Noreps and RISA. Other key stakeholders such as MIDIMAR, RAB, RWFA and MINALOC provided expertise on the current challenge of weather data collection and needs for effective disaster risk management and agricultural planning. The local community such as officers from Kayonza District were very helpful in helping to understand the problematic at the district and sector levels. Finally, sector agronomists and smallholder farmers provided specific insights into the needs of the community.

Below is a detailed list of stakeholder that were engaged during this first phase as well as an expanded list of stakeholders to be potentially engaged during the next phases.

#### Stakeholders engaged during the pilot phase:

- Meteo Rwanda
- University of Tokyo
- Ministry of Disaster Management and Refugee affairs (MIDIMAR)
- Ministry of Local Government (MINALOC)
- Rwanda Agriculture Board (RAB)
- Rwanda Water and Forestry Authority (RWFA)
- Rwanda Environment Management Authority (REMA)
- Rwanda Utilities Regulatory Authority (RURA)
- Tumba College of Technology (TCT)
- Local leaders Kayonza District
- Murundi, Ndego and Rwinkwavu Sectors
- Sector agronomists
- Farmer facilitators and Smallholder farmers

#### Stakeholders mapping for future phases

#### International stakeholders

Development partners (e.g. JICA, USAID, NOREPS, Red Cross, World Bank, ADB, SIDA, KOICA, DFID); UN agencies (UNDP, FAO, WFP, UNHCR, ITU)

#### National stakeholders

MIDIMAR, MINIRENA, MINALOC, MINAGRI, MITEC, MINEDUC, MoIT, Meteo, RAB, RURA, RWFA, REMA, RDB, RISA, NCST, CGIS/UR

#### Local community

Districts and sectors, local NGOs, District officials, Sector agronomists, Farmer facilitators and promoters

> Key stakeholders Meteo Rwanda, UNDP, MoE, MIDIMAR, RAB, RWFA, REMA, District and Sector Officers

Figure 10. "Map your stakeholders" tool from UNDP Project Cycle Hackers Kit

#### Key stakeholders:

• Meteo Rwanda, UNDP, MoE, MIDMAR, RAB, RWFA, REMA, District and sector officers

#### Local community:

- Districts and sectors
- Local NGOs
- District officials
- Sector agronomists
- Farmer Facilitators and Promoters

#### National stakeholders (including Ministries and Government institutions) Ministries:

- Ministry of Disaster Management and Refugee affairs (MIDIMAR)
- Ministry of Environment (MINIRENA)
- Ministry of Local Government (MINALOC)

- Ministry of Agriculture and Animal Resources (MINAGRI)
- Ministry of Information Technology and Communications (MITEC)
- Ministry of Education (MINEDUC)

#### **Government institutions:**

- Rwanda Meteorology Agency (Meteo Rwanda)
- Rwanda Agriculture Board (RAB)
- Rwanda Utilities Regulatory Authority (RURA)
- Rwanda Water and Forestry Authority (RWFA)
- Rwanda Environment Management Authority (REMA)
- Rwanda Development Board (RDB)
- Rwanda Information Society Authority (RISA)
- National Council for Science and Technology (NCST)
- Center for Geographical Information System and Remote Sensing (CGIS/UR)

#### International stakeholders:

- JICA
- USAID
- SIDA
- KOICA
- DFID
- Norwegian Emergency Preparedness System
- Norwegian People's Aid
- Red Cross
- World Bank
- African Development Bank
- Other development partners and NGOs

#### **United Nations agencies:**

- United Nations Development Program (UNDP)
- Food and Agricultural Organization (FAO)
- World Food Program (WFP)
- United Nations High Commissioner for Refugees (UNHCR)
- International Telecommunication Union (ITU)

**Indirect stakeholders:** Research institutions and higher learning institutions, CoEs, Telecom companies, Security organs

- Tumba College of Technology (TCT), University of Tokyo
- Rwanda ICT Chamber, Klab, FabLab, CGIAR, Carnegie Mellon Rwanda University (CMRU)
- Centres of Excellence (CoE); including the Africa CoE in Internet of Things (ACEIoT); CoE in Biodiversity & Natural Resources Management; Global Climate Observatory in Partnership with MIT and COMESA; East Africa Centre for Fundamental Research (EAIFR) as a partner institute of the International Centre for Theoretical Physics (ICTP)
- Kigali Innovation City

## **2.4 Opportunities and potential of IoT for Climate**

In this section we discuss the opportunities and potential of IoT for climate change adaptation. Piloting this initiative has served to identify what are the main opportunities in the context of Rwanda and to fully grasp the potential of the initiative for reducing the vulnerability of the population to climate change.

IoT technologies and applications are proliferating and have a great potential in the fight against climate change. The rapidly growing network of connected objects and devices is affecting the lives of people not only in industrial countries, but also in emerging and developing countries.<sup>15</sup> There are already many examples of how IoT is improving lives in developing contexts, particularly relevant to this report, in sectors such as agriculture and disaster risk management. As mentioned previously in this report, the rapid proliferation is supported by how the cost of IoT technologies is low and continues to decrease. IoT sensors can be much cheaper than conventional meteorological stations and can therefore be distributed to many more locations (cells), creating a dense observational network. Furthermore, huge amounts of data collected from IoT technologies can be processed quickly and transformed into accurate and actionable agricultural information and advice.

The Government of Rwanda is committed to advance ICTs for development and to the Internet of Things, creating an enabling environment for initiatives like this one. There is also a growing number of institutions in Rwanda with the technological capacity to work with IoT technologies and applications and big data processing/analysis. For example, an African Centre of Excellence in Internet of Things (ACEIoT) was recently established and is hosted at the University of Rwanda.

Other opportunities relate to the increased internet penetration and mobile connectivity. Internet penetration in Rwanda increased from 7% in 2011 to 39.76% mid 2017.<sup>16</sup> In particular, internet penetration in rural areas is expected to increase thanks to the "smart village" program. On the other hand, mobile connectivity that is affordable for all makes it possible to get in touch with new target groups like smallholders that were difficult to reach before and to process feedback from these groups. From the assessment of user profiles carried out in the District of Kayonza, it was seen that most smallholder farmers have feature phones and most sector agronomists have smartphones. Mobile subscriptions increased from 639,673 to 9.7 million over the period 2010 -2017,<sup>17</sup> with the three main mobile operators being: MTN, Tigo and Airtel.

Lastly, another key opportunity is the strong support of key stakeholders to this initiative. Meteo Rwanda has led this pilot project from the design stage and is committed to supporting IoT initiative for better climate data. Other key stakeholders have also shown their interest in supporting the further scale up phases.

<sup>&</sup>lt;sup>15</sup> GIZ and Betterplace Lab (2015). Internet of Things. Using sensors for good: How the Internet of Things can improve lives. Berlin: BMZ.

<sup>&</sup>lt;sup>16</sup> Ministry of Information Technology and Communications (2017). ICT Sector Strategic Plan 2018 - 2024.

Towards digital enabled economy.

<sup>17</sup> Ibid

By leveraging these opportunities, the IoT for Climate initiative can have a meaningful impact in reducing the vulnerability to climate change. Better climate data collected through IoT technologies can lead to more timely and accurate climate information that is used for better agricultural planning, Early Warning and Disaster Risk Management, water management and to address other environmental concerns. Moreover, the initiative has the potential of strengthening the IoT industry overall, contributing to "Made in Rwanda" technology and promoting employment and business opportunities.

The below subsections explain more in detail the potential of the IoT for Climate initiative in terms of:

- Reducing vulnerability of people to climate change by , for instance, supporting agricultural planning and Early Warning
- Monitoring the environment in general
- Strengthening the IoT sector in Rwanda



Figure 11. Potential of IoT for climate change adaptation

# **2.4.1** Reduced vulnerability to climate change and mitigation of disaster risks and other weather and water-related issues

Disaster Risk Reduction is a conceptual framework that entails minimizing disaster risks by reducing the degree of vulnerability and increasing resilience capacity as well as preventing or limiting the adverse impacts of natural hazards with a sustainable development approach. Acknowledging that there is nothing natural about disasters, but that these can actually be avoided and their impacts minimized, this project is presented as an initiative to collect and disseminate reliable weather and climate data to reduce the vulnerability to climate change and increase the resilience of vulnerable populations to disaster.

Rwanda is a country highly prone to disasters such as drought and flood; however, the country faces an ongoing challenge of collecting timely and accurate data that can help vulnerable populations and decision-makers be better prepared for climate change. Drought affects the population who depend on rain waiter to cultivate and get agricultural products, especially in the Eastern province of the country. In response to this, MIDIMAR developed the National Drought Contingency Plan to ensure that necessary efforts are carried out to mitigate the risk to drought. The plan serves as a tool to support the preparedness, response and recovery intervention in case the country or a given district faces the impact of drought. While the plan contributes to the improvement of early warning systems for drought detection, reporting mechanisms and cross-sector collaboration, the challenge remains getting accurate forecast data for a specific location since the data being used are generalized at the district level.<sup>18</sup> In this regard, micro-level climate data becomes very relevant for reducing climate related risks.

Emerging Internet of Things (IoT) technologies have the potential to collect and disseminate more accurate microclimate data. IoT devices such as wireless sensor networks, network-connected weather stations, cameras and smartphones, can be used to collect a vast amount of climate data which is then stored in the cloud. Such data can then be analysed to compute localized data and recommendations for any specific location. Real-time micro data collection and dissemination can support decision making at the population level (farmers, direct early warning) and the policy planning level (DRM, agricultural planning) to reduce vulnerability to climate change related issues such as drought and flood. For instance, precise real-time information can help manage water in response to drought.

IoT solutions have the potential of being widely implemented in development contexts due to various factors, including a decline in the price of IoT sensors by about 80-90 percent over the past five years; an increasing internet penetration and the falling cost of smartphones; and the increasing support by governments in developing nations towards IoT innovations.<sup>19</sup> Programmers and designers are constantly developing new low-cost IoT applications that can help solve development challenges. Installing more internet enabled weather stations or small-scale IoT devices can contribute to having a denser observational network which is capable of providing real-time microclimate and weather data. The data collected from IoT technologies can be combined with data

<sup>&</sup>lt;sup>18</sup> MIDIMAR (2017). Presentation on the Importance of micro-scale climate data for Drought disaster risk management.

<sup>&</sup>lt;sup>19</sup> GIZ and Betterplace Lab (2015). Internet of Things. Using sensors for good: How the Internet of Things can improve lives. Berlin: BMZ, pp. 8.

collected from Meteo's manual and automated weather stations, improving the weather forecasts. Working closely with Meteo, capacities can be developed to assimilate data from various different sources, including ground and satellite, as well as to improving the forecasting models. Furthermore, applications can be developed to collect feedback from users on site, who may tell whether the forecast was correct or not, helping improve the models and ultimately adding precision to these forecasts.

Based on the data collected from IoT technologies and conventional weather stations, data usage applications can be developed to disseminate the climate data in an effective and understandable way to vulnerable populations and planners, accelerating effective planning and decision-making in agricultural productivity, Early Warning, disaster risk reduction and water resource management in vulnerable areas.

More specifically, the use of IoT technologies and applications to collect and disseminate micro-level climate information in Rwanda has the potential to:

#### Improve provision of climate information for smallholder farmers to support agricultural planning

Based on the data collected, weather alerts and information and advisory services can be provided to smallholder farmers, who make the majority of the 83 percent of the population living in rural areas in Rwanda. In the face of climate change, smallholder farmers can no longer fully rely on traditional knowledge and require information and advice to protect their harvest and improve their agricultural practices.

Microclimate data can, for instance, assist insurance companies in the provision of services to smallholders. With more accurate data, the insurance can work better and farmers can be in turn more protected against climate change as well as more willing to take risks and try new farming practices.

#### Set up an Early Warning system

Better climate data can contribute to the design of early warning systems, improving preparedness and significantly reducing the losses for vulnerable populations to disasters such as drought and floods. As explored in section 2.2, there is a strong need for setting up an Early Warning system in Rwanda, coordinating closely between Meteo Rwanda and MIDIMAR.

IoT sensors can contribute to data feeds about weather and climate in real-time, anticipating problems and putting defences in place to mitigate their impact. Weather and forecasting models can use this data and integrate it with data from other sources to predict disasters. If a climate hazard occurs, communities can be alerted via different channels, including SMS or even sirens to evacuate the population. IoT-enabled devices also have an advantage in terms of data network resilience in face of a disaster. Often battery powered and able to operate and transmit wirelessly, IoT-enabled devices could enable limited communication services, such as emergency micro-message delivery, in case the conventional communication infrastructure stops working.<sup>20</sup>

#### DRM planning and response

<sup>&</sup>lt;sup>20</sup> GIZ and Betterplace Lab (2015). Internet of Things. Using sensors for good: How the Internet of Things can improve lives. Berlin: BMZ, pp.16.

Improved weather forecasts on a regular basis (daily, weekly, quarterly and seasonal) can inform the Disaster Risk Management planning process and disaster contingency, preparedness and response plans. Furthermore, microclimate data could be used for comprehensive risk assessments as well as for disaster monitoring and reporting.

Better climate data can contribute to humanitarian response to disasters. Big data can play a key role in the response during and in the aftermath of a disaster. Localized data collected can support disaster strategies such as where to direct aid response or how to move those at risk to safe locations. IoT technologies, such as drone footage and satellite mapping, can help identify the communities that are in crisis during and after an emergency. Additionally, the deployment of IoT devices, which are often battery powered and able to transmit wirelessly, could become an alternative communication system in face of a disaster. The devices could enable limited communication services in case the conventional communication infrastructure fails and is out of service.

#### Water management

In view of increasing water related challenges, better climate data can lead to improved water resources management practices. For instance, dams can be operated on the basis of inflow forecasting (which uses rainfall data) and irrigation systems can be optimized based on weather parameters such as evaporation, wind speed, soil moisture and temperature data. Working in close collaboration with the Rwanda Water and Forestry Authority (RWFA), climate data could be used to improve the hydrologic models and to better predict hydrologic processes and understand and manage water resources.

Overall, IoT technologies and applications can help build the resilience and increase the preparedness of vulnerable populations facing climate change and weather unpredictability.

## 2.4.2 Environmental monitoring

IoT technologies can be used for monitoring the environment in general, helping inform decision making and planning. As human populations grow, so do the resource demands imposed on ecosystems. Natural resources are however limited and therefore need to be better protected and managed. IoT sensors can help monitor the quality of air and water, forests and protected land, as well as biodiversity, among others. Working closely with the Rwanda Environment Management Authority (REMA), this initiative could for instance support the monitoring of air quality in the city of Kigali. As cities become more densely populated, they face an increasing challenge of poor air quality, which has detrimental impacts on the health of citizens. Monitoring the air quality will help inform decisions in order to reduce the pollution, contribution to less respiratory and other diseases.

## 2.4.3 Strengthening the IoT sector

The initiative IoT for Climate in Rwanda has the potential of strengthening the IoT industry in the country, contributing to the creation of new business start-up opportunities as well as the creation of

<sup>&</sup>lt;sup>21</sup> Ibid, pp. 16.

new jobs. It is linked to the government's efforts to expand Rwanda's commitment to IoT and to becoming a service-based economy. Through knowledge transfer and capacity building, the initiative is further contributing to "Made in Rwanda" IoT technology.

As documented in the Rwandan Vision 2020, the service sector is believed to be the engine for the economy with a growth rate of 13.5 percent and a contribution of 42 per cent to GDP. Furthermore, Rwanda has recognized the importance of Science, Technology, Research and Innovation (STRI) for the country's development. STRI capacity in Rwanda has expanded over the past ten years through government, donor, and private sector investment. To operationalise the STRI Policy objectives, the Government has taken various actions. For instance, it is establishing various Centres of Excellence (CoE), including the Africa CoE in Internet of Things (ACEIoT) with support from the World Bank and the CoE in ICT in Collaboration with Carnegie Mellon University and the African Development Bank. Other initiatives to advance Science and Technology in the country include the Kigali Innovation City, an innovation hub to support tech companies and innovation. The Rwanda Information Society Authority (RISA), a partner in this project, is playing a key role in accelerating the digital transformation of Rwanda's economy and promoting emerging technologies, including IoT.

In line with the government's efforts, this IoT for Climate initiative proposes technology transfer and capacity development from upstream engineering to downstream data application. The pilot initiative showed how working in collaboration with partners, such as the University of Tokyo (UoT) from Japan, allowed for the transfer of technology. UoT trained Tumba College of Technology (TCT) graduates on how to assemble, set up and maintain the IoT devices. Sector officers in Kayonza District were also trained on the concept of IoT and the maintenance of the devices. This approach strongly contributes to "Made in Rwanda" technology. There are further potential business and employment opportunities in the commercialization and maintenance of these IoT technologies. Working in collaboration with other development partners, including cooperation agencies and development banks, could help strengthen the transfer of different IoT technologies, not only limited to the sensors used for the pilot project, but for instance drones to create location-specific GIS data, which could be integrated with satellite data.

After installation of IoT technologies, data is then stored in the cloud and needs to be processed and analyzed. The initiative also has the potential to transfer knowledge on big data management, processing and analysis. Technology transfer can take place at institutions with the technical capacity such as kLab, Carnegie Mellon Rwanda University (CMRU), and ICT Chambers, to boost data processing and tool development capacity through training and on-the-job training with scientists from research centers with scientific records for establishing big data processing and accumulation, such as the University of Tokyo and National Institute of Advanced Industrial Science and Technology (AIST) from Japan.

Lastly, applications can be developed based on this micro-level climate data collected through IoT technologies. This component refers to the concrete creation of startups that will form the IoT industry and lead to the creation of employment opportunities. By building capacities of entrepreneurs and programmers/tech experts, promoting PPPs, providing seed funding and support; these initiatives can become sustainable businesses.

## **2.5 Challenges of IoT for Climate**

When using IoT technologies and applications for climate change adaptation in the context of Rwanda, there are various challenges and considerations that need to be taken into account, which include those in relation to the collection, assimilation, dissemination and usage of climate related data.

#### Data collection

Better climate data can be collected through the use of IoT technologies, which can range from small-scale devices to more complex automated weather stations. There is a trade-off between small scale IoT devices and more complex automated weather stations which meet WMO standards. Using small-scale IoT devices could potentially be deployed in more locations, helping collect more localized data in Rwanda; however, there are some drawbacks that need to be considered. The monetary cost of small-scale devices with a limited number of sensors is indeed markedly lower than that of the weather stations; yet they do not have the full array of sensors of a weather station. Weather prediction modeling however relies on a number of inputs, including humidity and temperature, rainfall, wind speed, wind direction, and sunshine. This means that measuring few indicators with small-scale devices would not be useful for improving weather predictions, and creating an IoT device that has the full capabilities and standards of a weather station would remove the price advantage and takes a significant amount of time to perfect. Before opting to develop a new device, it is useful to look at other small IoT weather stations developed in the region that are acting as cheaper alternatives to large automated stations.

Small-scale devices could be built at a relatively low cost if not compliant with WMO standards. However, this poses a challenges in terms of the usability of the data collected. Meteo, as all other meteorological agencies, requires the data to be to the standards of WMO in order to use it for its forecast. Making the device WMO compliant guarantees the use but in turns raises the costs. Furthermore, the advantage of small, cheap, IoT devices is apparent when there is a need for a large network of devices which record one or two metrics.

During the pilot project, small-scale and low cost IoT sensors were set up in the Kayonza District to measure soil moisture, temperature and humidity. From the experience of assembling and setting up the devices, key challenges were identified which are to be considered moving forward:

- There is not a sensors market in Rwanda, which means the readymade sensors need to be sourced from outside. In the case of the pilot project, the sensors were sourced from Japan increasing the overall costs.
- The design of the data transmitting boxes requires a lot of testing and more investment in order to be a good functioning final device that lasts and is resistant.
- Maintenance and diagnosis of the devices is quite challenging and requires a lot of effort. For instance, during the pilot phase 12 sensors were installed but only 5 were working properly and transmitting data after two months. The sensor analysis conducted in Phase Two showed that the devices from Rwinkwavu were only transmitting information for about one month. This is attributable to a power failure caused by either the solar panel breaking

off or becoming so dirty that is ceases to function. Within the month the IoT sensors were transmitting, there is a slight difference between the IoT data and Meteo's own readings. Comparing temperature, it is clear that while most of the time the IoT sensors matches Meteo Rwanda, they consistently reach higher peaks than the WMO standardized Meteo readings. This could be attributed to a need for calibration or improper sensor placement; at Rwinkwavu we discovered that the temperature sensor had been placed inside a metal pole. While quality sensors and regular calibration are key, it is clear that the IoT sensor project cannot function without the sector-level stations' help in maintenance and diagnostics.

Either going for small-scale IoT devices or for internet enabled weather stations, there are some general challenges which need to be considered as well:

- Security concerns intrinsic to IoT: While IoT technologies are becoming part of everyday lives, the technologies pose a range of security concerns. IoT technologies depend on a range of devices that transmit and process information over the internet. Most devices have technical vulnerabilities and could be at risk to hacking attacks.
- Maintenance: the maintenance of IoT devices requires a lot of work. From the pilot project as well as from the experience of other initiatives in the region, maintenance requires particular attention. There need to be well trained people on the ground to make sure that the devices work well and that data is being constantly transmitted.
- Assembly: If the devices are assembled in Rwanda, the parts will need to be sourced from outside which increases the overall cost. It becomes crucial to make sure that the devices are assembled in such a way that they last. Key aspects to consider during the sensor assembly include the IP rating enclosure and environment, which are standards used to define the levels of sealing effectiveness of electrical enclosures against intrusion from foreign bodies such as dirt and water. The sensors must be well protected from the environment; from rain, dust, and particularly in Rwanda, from UV light. For this, a good electrical enclosure is needed as well as UV resistant cables. Other aspects to consider include which power supply to use; the endurance; and the communication, whether to use GSM, RF, WAN, or LoRaWAN.
- Safety of the field sensors: In many data monitoring projects, theft of sensors and solar panels have been an issue. In order to cope with this challenge, the project is engaging MINALOC in the design stage and also utilizing existing Meteo observatory sites.
- Electricity: Electricity remains a challenge in Rwanda. While the IoT devices can be sustained with solar panels, the data transmission requires electricity. If the electricity is out, the transmission needs to be rebooted by someone on the ground.
- Connectivity: Internet instability still remains a problem in Rwanda, especially in rural areas of the country.
- Big Data accumulation and analysis: On the software backend of the IoT technologies key challenges relate to how the data is accumulated for further processing and analysis. Key aspects to consider:
  - What kind of data do we want to store? How much data will be permanently stored? Based on this, the right database can be selected, e.g Time Series (openTSDB, InfluxDB, etc), SQL or NOSQL
  - Too much data can be a problem. Data can be compressed, packaged and sent to the server fewer times, which will also reduce costs. It is important to be particular on the data that is needed and not to get as much as possible. Data can become

outdated quickly, which is why a high resolution may be needed at the beginning, but afterwards it could be lower, saving time and costs.

- How to make sense of all the data that is being accumulated? In order to visualize and make sense of the data retrieved, a dashboard needs to be chosen. There are many dashboard options, so it may not be necessary to recreate one.
- Investment/financial: Whichever technology is used there will need to be a big investment. Models for cost recovery need to be explored as well as partnerships with organizations that have already tested and are deploying such IoT technologies in the region.

#### Data integration and assimilation

While more granular weather measurements could potentially lead to better weather predictions, there need to be capabilities in place to harness such granular data. Meteo Rwanda needs to have the capacity to assimilate the data from IoT technologies in order to improve its forecasting models.

The data retrieved from the IoT technologies must be compliant with WMO standards for it to be included in the official weather forecasts. While the data could be presented as a separate weather index, it may advisable to make it WMO compliant to guarantee its use by Meteo.

While the data from IoT technologies could potentially help improve weather predictions, it will not necessarily enable accurate predictions of natural hazards such as droughts. Drought continues to be the least understood of all natural hazards. Although droughts are initiated by an extended precipitation deficiency, monitoring precipitation only is not sufficient to assess the severity and impact of a drought. Effective drought monitoring systems require much more, integrating precipitation frequency and intensity and other climatic parameters with different types of water information into a comprehensive assessment of drought and water supply conditions.<sup>22</sup> Due to the complexity of droughts, a comprehensive and integrated approach which considers many indicators is needed for drought monitoring and early warnings.

Lastly, there needs to be clarity and coordination among different government institutions responsible for different types of data. There also need to be mechanisms and tools in place to integrate data collected from IoT technologies with data from other institutions, for instance from MIDIMAR if the purpose is to set up an Early Warning system.

#### Data accessibility, dissemination and usage

While the data collected from the IoT sensors can improve climate information, its access needs to be strongly enabled. Prior to this pilot project, Meteo did not have an API in place which made it difficult for developers to openly access climate data. In the scope of this project, an API was developed and installed in Meteo's server. Accessibility to data collected from IoT technologies features to a few key challenges. The first is the reliability of the API in place. One must make sure that the API server is running and that the network is properly configured. Moreover, it is difficult for developers to access an API if it is only accessible via an IP address (e.g. 123.456.78.9). The API administrator must make sure to map the publicly facing IP address of the API server to a

<sup>&</sup>lt;sup>22</sup> Information systems in a changing climate: Early warnings and drought risk management <u>https://www.sciencedirect.com/science/article/pii/S2212094714000218</u>

human-friendly domain name (e.g. api.meteorwanda.gov.rw). While these challenges are not so difficult to mitigate it is important that someone is in charge of maintenance to ensure that there is no disruption of service.

Once better data is being collected, assimilated and made accessible, this data needs to be turned into reliable climate information that can inform decision-making and better planning to reduce vulnerability to climate change. New applications can be built to deliver climate information for better agriculture planning and early warning, among others. These new applications can be built directly by Meteo Rwanda but also by other actors.

On this end there are also some challenges to be considered. There needs to be the awareness and skills to fully use new climate information products and services. For instance, delivering climate information to smallholder farmers involves working with a relatively new market segment. Smallholder farmers may be less predisposed to new services and products. They often lack education and skills and have limited or no access to capital or resources for investment, and are therefore traditionally risk averse.<sup>23</sup> This means that smallholders will need to be convinced that a new service or product they will user (or buy) will actually benefit them. This is something to be strongly considered by the entrepreneurs and technology experts who develop new IoT applications for the dissemination of climate related information. It will be necessary to build trust among the end users. Another challenge on the farmers' side relates to the possession of smartphones. While great progress has been made in terms of mobile connectivity, smallholders still have feature phones as opposed to smartphones. This means that new applications have to be developed taking into account these characteristics. In this same line, if early warnings are disseminated to local communities, user will need to have the awareness and know how to respond to such information.

Developing useful technology solutions require much prototyping and testing. In order to accomplish a good climate information service or product, there will need to be many rounds of iteration; technology solutions are never final. Furthermore, while being from Meteo Rwanda or other actors, the solutions must have good business models in place and be sustainable in the long run.

The dissemination of information to vulnerable populations will further require strong coordination between different government bodies. For instance, disseminating information to farmers requires inputs and coordination with agencies like RAB. On the other hand, setting up a good early warning system in place requires strong coordination with MIDIMAR and other agencies involved in disaster preparedness.

<sup>&</sup>lt;sup>23</sup> G4AW (2016). A Business Case for Opening New Markets using Satellite Data for Smallholder Farmers and Pastoralists in Developing Countries.

#### General considerations related to the sustainability of the IoT for Climate initiative:

- An important challenge refers to the financial sustainability of this initiative. Strategies for cost recovery need to be tested. Similar initiatives in the region have been trying various different business models, but they are still finding self-sustainability a challenge. Additional funding from other sources will also need to be explored.
- Building partnerships with the private sector will be highly beneficial for a project working on the use of new technologies as IoT. Efforts should be put into engaging private sector companies and entrepreneurs.
- Keeping key stakeholders engaged will be crucial for the success of this initiative and maintaining conversations with them is necessary for identifying well the needs and preferences.
- Reconciling the innovation approach of this project with processes and procedures of UNDP and the government will support keeping the project relevant, building on learnings, and making the best use of new IoT technologies.

# **Chapter 3: Lessons learned and scaling up IoT for Climate**

## **3.1 Lessons learned**

This part is intended to capture some key lessons learned from the implementation of the IoT for Climate pilot project.

**Stakeholder engagement** is crucial to increase impact and ensure the sustainability of the project. Stakeholders provided key insights into the problem of obtaining accurate climate data and information and the specific needs of the sectors in the Kayonza district.

A **user-centered approach** ensures that the project meets the needs of the population. An understanding of the user needs and profiles was possible through stakeholder meetings and user interviews during field visits. Key findings from the interactions with the users during Phase One included: smallholder farmers need accurate and packaged micro-level data; farmers do not fully trust the forecasts since these are general to the sector level; farmers mostly have feature phones; sector agronomists do have smartphones and receive weather information via whatsapp groups. During phase two, a user-centered approach allowed a clear understanding of the gaps along climate information for early warning.

**Prototyping and testing** at every stage of a project like this one is useful for making sure that the solutions work and meet the needs of users. While this was done during the pilot phase, more testing needs to be done in order to ensure that IoT technologies works well. On the usage side, solutions need to be iterated, ensuring that they serve the ultimate purpose of improving agricultural productivity and reducing vulnerability of people to disasters. On this same note, it was important for the project to recognize that technology solutions are never final, and require continuous iteration.

**Innovation projects** such as this one change over the course of their implementation, requiring adaptation and flexibility from project managers and implementers. As new learnings keep on being identified, project actions need to be quickly adapted. Below are some detailed learnings regarding the use of an innovation approach in this project.

- The innovation approach has proven beneficial in that it allowed rapid prototyping and testing which led to quick learnings. Also, it allowed the continuous engagement of end users, stakeholders and non traditional actors such as young programmers and developers.
- However, there is a friction between such an innovation approach and the UNDP and government's business as usual approach. The organizational processes and procedures as well as the more traditional project management culture presents certain challenges: processes are lengthy, quick adaptations are challenging, the traditional reporting and measurement of accomplishments is not aligned to the innovation mind-set, where failure is embraced, among others.
- Efforts need to be put into bridging the gap between innovation and business as usual. For
  instance, Public Procurement for Innovation proved to be useful for awarding prizes to
  innovative climate information solutions during the Design-a-thon for Climate in the pilot
  phase one. Innovation challenges are defined as prized challenges that Country Offices

organize to solicit innovative ideas and solutions to address development challenges which cannot be achieved through traditional solicitation processes. By doing open public procurement and requesting performance-based technical specifications that are open ended, UNDP left room for innovation.

The co-creation and rapid prototyping of innovative solutions to climate information challenges was possible through innovative design thinking and hackathon-style methodologies. These methodologies support innovation and the design of user-centered solutions, but require the understanding and trust from all stakeholders involved in the project. More time needs to be invested in making sure project managers and stakeholders see the value and leverage such processes, clarifying roles of experts in hackathon-style events, ensuring jury members understand the criteria for judging innovation prototypes, among others.

**Capacity building** is a key component of this initiative and should continue being incorporated in all aspects of the climate information chain, from collection to usage. This will ensure the success of the initiative as well as contribute to a stronger IoT/technology sector in the country. So far, the project has focused on building capacities of key government stakeholders, sector officers and Tumba College of Technology graduates and students on IoT technologies and issues related to maintenance, security and connectivity. It also built capacities of young programmers and developers to design useful climate information applications and prototype solutions to Climate Early Warning challenges.

**Collaboration** with other projects and actors is needed for the scale up and sustainability of this initiative. Other actors range from national stakeholders, to private sector and entrepreneurs working on IoT to similar projects in the region. The project should particularly take advantage of the fact that many actors in the innovation and technology scene are willing to collaborate, both at the national and regional level.

Working on using IoT to improve climate information requires understanding and working on all areas of the value chain: **collection, assimilation, dissemination and usage**.

- Using IoT technologies can be powerful for improving the collection of climate data. However, there are key consideration related to the durability and maintenance of such devices. Besides quality sensors and regular calibration being key components, it is also clear that the IoT sensor project cannot function without the sector-level stations' help in maintenance and diagnostics. Furthermore, there are other actors with record in using IoT technologies for climate data collection that can support the success of this initiative.
- Assimilating data from IoT technologies requires strengthening capacities at Meteo Rwanda as well as coordinating with other institutions for integrating different sets of data.
   For instance, integrating Meteo Rwanda data with MIDIMAR data con prove very useful for Climate Early Warning.
- Climate data becomes relevant only if it translates into usable climate information. Not all climate information applications need to be in the domain of Meteo Rwanda, but other actors can innovate and build useful products if access to the data is enabled.

## **3.2 Scale up guideline**

This section aims to capture some strategies that can guide the scaling up this initiative to the national level and in the future to other Sub-Saharan countries, taking into account the challenges and opportunities in sections 2.4 and 2.5.

In particular, the success of any data or IoT project depends upon successfully addressing each part of the climate information chain:

- 1. Data collection weather stations, IoT sensors, weather volunteer records, satellites, etc.
- 2. Data assimilation and integration combining data from different sources into useful information
- 3. **Distribution** enabling different institutions and stakeholders to use the data collected and the information generated from that data
- 4. Usage final endpoint users use the information to make decisions, such as smallholder farmers and vulnerable population

Based on the learnings from the pilot phase, there are some specific areas that fall more directly in the scope of this project and that are urgent priorities. The following sections explore scale up guidelines as well as suggested steps for the next phase of this project.

### 3.2.1 Guidelines for scale up

#### Guideline #1: Scale up solutions after piloting and testing

During Phases One and Two of the project there were prototype solutions to gaps along the climate information chain. These solutions have the potential of being fully developed and institutionalized, improving the collection, assimilation, dissemination and usage of climate data and information.

Further development would require more rounds of iteration, by which solutions continue being tested for feedback and feedback is incorporated until they serve better the needs of vulnerable populations. After various rounds of iteration, the solutions will be ready for scaled up.

The graph below show the different solutions that have been prototyped during the pilot project.



Figure 12. Solutions to improve climate information prototyped during Phases I and II

# Guideline #2: Focus the strengthening of Meteo Rwanda in data quality control, assimilation and coordination

Based on the project learnings, the priority will be on strengthening Meteo Rwanda capacity in collecting quality data and in assimilating data, as opposed to focusing on developing new climate information products/applications. Instead, the API installed on Meteo's server can be leveraged allowing other actors to build new applications. Accessibility to Meteo's data can continue to be improved so as to increase the usage opportunities by broader actors outside public institutions.

This leaves room for Meteo Rwanda to focus on strengthening its network of data. The improvement of the existing network of automated stations will be partly covered through UNDP's 5 year programming. Within the scope of this innovation project, the priority can be on using new IoT technologies and data, such as sensors or small scale weather stations, either directly by Meteo or through partnerships. Specific activities for the next phase are explored in the following section.

With better climate data being collected, Meteo Rwanda will also need to focus on strengthening its weather and hazard modelling. With the support of UNDP's 5 year programming, capacities of the forecasting staff and modelling software will be further improved. This project can instead focus on testing solutions that already came out from Phase One and Two. For instance, the project can test improving forecasts based on feedback received from users on the accuracy of the current forecasts. It can also look at further testing the integration of data between Meteo Rwanda and other institutions' data, such as that of MIDIMAR. This requires strong coordination between the different institutions.

# Guideline #3: To fully benefit from the concept of IoT leverage on the private sector and entrepreneurs ecosystem

Engaging the private sector will be essential for creating an enabling environment for technology innovation. The project should look for continuous collaboration with private sector initiatives on IoT, which could be done in multiple ways. For instance, it could focus on building partnerships for the expansion and maintenance of the IoT data collection network, taking advantage of private sector actors that have experience with small scale weather stations or other sensors. It could also invite the private sector to submit data from IoT devices to supplement and calibrate to Meteo's data. Finally, the project can focus on allowing entrepreneurs to build new applications by enabling the access to Meteo's data. Collaborating with the private sector will not only enhance better climate information but contribute to a stronger IoT industry.

#### Guideline #4: Strengthen partnerships with other existing projects and stakeholders

Through the experience of this pilot project and similar initiatives in the region, a key lesson learned is that multi-stakeholder partnerships are necessary when it comes to using new technologies to improve climate information with the ultimate purpose of serving the needs of vulnerable populations. The project should continue focusing on building strong partnerships with relevant actors. For example, the project has so far benefited from knowledge transfer from University of Tokyo, and access to the innovators ecosystem and to design thinking and hackathon-style methodologies by working with Impact Hub Kigali, among others. It should further explore a strong collaboration with Rwanda Information Society Authority, which can support the prototyping, development and scale up of solutions identified in Phases One and Two as well as support capacity development efforts for young people and stakeholders.

Furthermore, collaboration can be strengthened with similar initiatives that are working on the use of technologies for better climate information. So far, potential technical partners such as TAHMO have been identified. TAHMO has already collaborated with Meteo Rwanda and is willing to continue working together.

#### 3.2.2 Suggested outputs and activities for Phase Three

Taking into account the guiding rules for scale up, Phase Three of this project could particularly focus on the following outputs and activities.

#### Output 1: Proven prototypes fully developed and institutionalized along the value chain

The prototypes developed during Phase One and Phase Two of the project can be fully developed and institutionalized. In particular, the following activities are proposed:

- a) Improve the use of API for non-Meteo actors: The API has been installed in the server in Meteo Rwanda. The existing IT staff of Meteo Rwanda will need to ensure that the server is running and connected, and that it has all the right permissions to access Meteo's database. This will enable non Meteo actors to easily access the data and have the opportunity to build climate information applications and products.
- **b)** Bridge the farmers' application to RAB and test on the field: After further testing and development of the farmers' application, it can now be bridged to RAB for its roll out. As a first step, the application can be piloted in one of the districts to assess how it works and collect further feedback. After other rounds of iteration, the application will be ready for further deployment.

- As part of the piloting of this application, the feedback received from farmers can be incorporated to improve Meteo Rwanda's forecasting.
  - c) Bring together the 10 winning teams of Phase Two to collaborate to further develop the solutions: The solutions that came out of the Hackathon for Climate Early Warning can be further developed and tested during Phase Three of the project. For this, the 10 winning teams could come together to collaborate in the development. RISA can be a key partner for this activity.

#### **Output 2: IoT Climate data collection network expanded**

Climate data collected by Meteo Rwanda would improve through an increased network of technologies. Phase Three could focus on achieving an expanded IoT climate data collection network through the following specific activities:

- a) **Partner with proven actors on small-scale weather stations in critical areas:** Instead of developing new technologies from scratch, the project can identify actors with proven experience in using small-scale lower cost weather stations that are WMO compliant. These can be installed in critical areas prone to disasters and where stations' coverage is lacking.
- b) **Test the use of soil moisture in modelling specific disaster prone areas:** Through soil moisture sensors, the data collected can be used for hazards modelling. For instance, it could be tested to predict landslides.
- c) Create an open database to invite private sector and academia to send data: Besides efforts in expanding the network of IoT devices, Meteo Rwanda could benefit from data collected by other actors using IoT technologies.

#### Output 3: Capacity built on climate data and information management

- a) Capacity building on big data and cyber security: In order to process and analyze big amounts of data being collected by IoT technologies, there needs to be development of capacities.
- b) **Capacity building of stakeholders on the usage of new climate information:** As new products and services are developed, users need to be trained to make the best use of this climate information, for instance, for better agricultural planning and early warning.

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#### UNDP project related resources:

- Project reports
- Project concept note
- Project proposal

#### Interviews:

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- Dominique Mvunabandi, Severe Weather Consult
- Frank Annor, Field Director, TAHMO
- Benjamin Kwasi, Programme Manager, MUIIS
- Penelope Cabot, Head of Impact, Kukua
- Serge Senyana, Meteorological Applications Officer, Meteo

## Annex

# ANNEX 1: Existing initiatives in Rwanda that focus on IoT and other technologies for climate

#### **Enhancing National Climate Services initiative (ENACTS)**

The initiative is led by the International Research Institute for Climate and Society (IRI) and has been piloted in eight countries in Africa. In Rwanda it is being implemented in partnership with Meteo. The initiative aims to bring climate knowledge into national decision making by improving availability, access to, and use of climate information.

ENACTS focuses on providing reliable and readily accessible climate data at high resolution to national and local decision makers in Africa. It delivers climate data, targeted information products and trainings. As a result of the 1994 genocide, Rwanda has a long term disruption in its observational network. Under the ENACTS initiative, Meteo-Rwanda has created web-based "maprooms"<sup>24</sup> by merging satellite data with its station observations to fill gaps in both space and time. Through these maprooms, Meteo can provide high-resolution climate information products tailored to the needs of agricultural users.

More information: <u>https://iri.columbia.edu/resources/enacts/</u>

#### Rwanda Climate Services for Agriculture project (USAID/CCAFS)

The Rwanda Climate Services for Agriculture project is a four-year initiative (2016-2019), supported by USAID/Rwanda and coordinated by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The project seeks to improve agricultural planning and food security management through improved climate risk management. In particular, the project aims to improve the supply, communication and use of climate related information using products that are co-developed by both providers and users. The project builds on the Enhancing National Climate Services (ENACTS) approach, and the web-based "maprooms" created under this approach.

Utilizing participatory methods, the Rwanda Climate Services for Agriculture project aims to train agricultural extension staff, development NGOs and other intermediaries to integrate climate services into their ongoing work with farming communities in Rwanda, providing relevant climate information and advisory services. The Meteo maprooms allow these trained intermediaries to access location-specific data and graphs as they work with farmers and local decision makers.

Main partners include Meteo-Rwanda, MINAGRI, Rwanda Agriculture Board (RAB), International Centre for Tropical Agriculture (CIAT), International Livestock Research Institute (ILRI), World Agroforestry Centre (ICRAF), International Research Institute for Climate & Society (IRI) based at Columbia University and Reading University.

More information: <u>https://ccafs.cgiar.org/building-climate-services-capacity-rwanda#.WoPbK-huY2w</u>

#### Meteo and FAO platform

<sup>&</sup>lt;sup>24</sup> <u>http://maproom.meteorwanda.gov.rw/maproom/</u>

Meteo is currently embarking on a project with the FAO to develop an app to provide more weather information to farmers. The pilot is taking place in Rulindo, where the FAO has hired a consultant to develop a platform for the available climate services and data for farmers. The goal of the app is to facilitate climate information, advisory, and feedback. The app developer for FAO is currently testing the platform in the field, although it is not ready to share widely.

Although collaboration with this project did not work for the timing of Phase 1 of the IoT for Climate Initiative, collaboration with the FAO/Meteo project should be an integral part of any next steps.

#### **Severe Weather Consult**

Severe Weather Consult (SWC) is a company based in Rwanda that focuses on developing weather services to help people anticipate to changing weather and mitigate climate related risks. It was first piloted in Musanze, a city that has experienced substantial damage from flood and lightning. SWC noticed that severe weather prediction systems are not very reliable and that there are no systems in place to gather lightning information as well as no effective channels for delivering it in a timely way to residents. Based on this, SWC is developing the iHewa platform which combines satellite weather data with ground weather and lightning sensor data to generate localized weather, floods and lightning predictions. The technology uses innovative low-cost lightning detectors to track lightning strikes of an area.

These predictions are then translated into meaningful information that is passed to citizens and consumers of weather information via phone (SMS, USSD and mobile apps) or weather platform and geo-portal. The iHewa platform aims to provide farmers and fishermen with weather and alerts related information followed by advisory services on appropriate fishing time, soil preparation, sowing and planting, crop calendar and monitor, among others.

Up to now, they have installed 15 automated weather stations with lightning sensors in the South, West and North of Rwanda, and one station is already collecting data.

### **ANNEX 2: Similar initiatives in the region**

Below are examples of climate and weather data initiatives in Africa and lessons learned.

#### Trans-African HydroMeteorological Observatory (TAHMO)

TAHMO is a not-for-profit NGO based in the Netherlands, Uganda, Kenya, and Ghana that aims to support the provision of hydro-meteorological services across Africa. It operates a network of about 400 weather stations in 18 countries. In Rwanda, TAHMO has an agreement with Meteo and is in the process of installing 15 stations, in collaboration with Severe Weather Consult. TAHMO stations use innovative sensor technology and ICT, becoming inexpensive and robust solutions that can provide critical data to governments, scientists and farmers in real time. It recognizes that for more accurate and localized data, there is a need for more ground weather stations. Ground weather data combined with satellite observations and computer models can ultimately help improve weather predictions.

It uses Meter Group MEM stations, which have been developed paying particular attention to African conditions. They are all-in-one weather stations, packaging 12 weather sensors which measure rainfall, temperature, humidity, wind speed/direction/gust intensity, solar radiation, lightning detection, GPS and local acceleration. The data is uploaded to the web on an hourly basis. The stations are mostly being placed at schools (primary to university), allowing students to use this data for their educational needs and helping foster a new generation of people with more climate resilience knowledge and interest in science. A teacher hosts the station and gets free access to teaching materials developed by TAHMO and free access to the data from that station.

TAHMO works closely together with the National Meteorological Agencies. Collectively they identify where to put the stations and choose schools in locations where there is a need for data. The initiative seeks to become a self-sustaining Public Private Partnership that creates an international weather and climate observatory to support the National Meteorological Agencies and international research community. Stations are provided to the Meteorological Agencies and TAHMO takes care of the maintenance and operations.

In order to ensure sustainability, TAHMO is still testing various business models. One way of recovering costs is to approach/offer data services to commercial entities interested in the data, such as insurance companies, solar energy companies and research institutions. Another way to ensure sustainability is through partnerships for the provision of climate and weather information to the end users. TAHMO is looking for startups/companies who can add value to the provision of climate information services. In Uganda, for example, it partnered with Airtel to offer weather related information to their subscribers free of charge and on-demand to promote customer loyalty. Another business strategy is to sell weather stations to individual clients such as schools or universities. In this case, a package is sold which includes the technology as well as installation and maintenance for three years.

More than the installation of the weather station, the main challenge is keeping the station operating for a long time and generating reliable data. TAHMO has trained and pays staff in the field who do the maintenance. The schools also play a minor role in supporting the maintenance of the station.

Another challenge is data assimilation. TAHMO does not do the weather forecasts, but partners with Meteorology agencies and other experts in weather forecasting who have the capabilities to assimilate data from various sources, such as ground and satellite data.

#### Key lessons learned:

- Ownership: Creating a sense of ownership is essential for the sustainability of the initiative, however, it is very costly and time consuming. Instead of installing the stations wherever TAHMO considered appropriate, it chose to engage in a long process to establish agreements with the Meteorological Agencies in each country, taking up to 2.5 years in some cases. This is costly and time consuming, but it ensures sustainability in the long term.
- Effective participation: Putting stations where the host feels responsible is also key for the sustainability of the stations. TAHMO engaged stakeholders in the process of setting up the stations. For instance, it discussed with school the duties and expectations, looking for a win win situation and making sure school are committed to the stations.
- Business model: Having a business model is a requirement for sustaining the project after the grants period and to ensure the the weather stations continue operating and providing reliable data.
- Capacity building: TAHMO trained local people as engineers for the maintenance/repair of the stations. Field staff are employed full time or part time and committed to making the station work.
- Compliance to international standards: At first TAHMO wanted the stations to cost less than USD 500, but in the end the cost ended up being much higher, about USD 1600, due to making the technology compliant to WMO standards. TAHMO noticed it had to make WMO compliant stations if the data was to be used by the meteorology agencies.

More information: <a href="http://tahmo.org/">http://tahmo.org/</a>

#### G4AW (Geodata for Agriculture and Water)

Geodata for Agriculture and Water (G4AW) is a program of the Dutch Ministry of Foreign Affairs, executed by the Netherlands Space Office. The program aims to improve food security in Sub-Saharan Africa and Southeast Asia by using satellite-derived information, which is more precise, location-based and therefore more reliable. The program stimulates public-private partnerships (PPPs) and supports initiatives that provide (information and advice) services and (financial) products that use satellite data to benefit smallholders. The program started in 2013 and to date it supports (with large grants for a period of three years) 17 projects, 7 of which are in South East Asia and 10 in Africa (particularly in Ethiopia, Kenya, Tanzania, Mali, Uganda and South Africa).

The portfolio of services offered through the G4AW projects is broad, with advice on pests and diseases and advice on water use and drought warning being at the top of the list. Other services include accurate weather information, advice on fertilizer application, crop monitoring and market information. Overall, the initiatives enable smallholders to increase production and productivity as well as provide a safety net in the form of increased resilience to disasters and through insurance schemes.

Of particular importance about this program is the emphasis on PPPs and use of different business models. G4AW encourages innovative PPPs bringing on board social development organizations, commercial partners, government organizations and academic institutions, each with their own unique capacities and capabilities.

#### Key lessons learned:

- While technical scalability is relatively easy, organizational upscaling becomes more difficult. In order to be successful in a different context, the business model and type of partnership require adaptation. In this regard, having a strong and active business partner with a good local network is crucial.
- G4AW projects have focused on identifying partnerships that help close "the information chain". For instance, in a closed information chain the satellite data provider collects free digital satellite data and processes with the appropriate technology; the tech and/or knowledge partner extracts information and knowledge to solve problems; the technology provider and commercial partner transmits information in an easy-to-use service for the farmer, the service delivery agent informs farmers of usage and applicability of the service; after which, farmers can use information and improve food security levels.
- A good baseline study of the demographics of the target group, user-demand, and challenges and opportunities for adoption is a necessary requirement for the success of a project. It also provides valuable information on the agricultural practices of the consumer.
- Once the target groups are defined, the next and perhaps most important step to be taken is to build trust. Smallholders need to be convinced that the service or product they are buying or committing to use will actually benefit their agricultural business.
- G4AW projects use satellite data for commercial or self-sustaining products and services. Self-sustainability depends on a wide range of business models that build on new innovative partnerships. Business models used include free service provision of basic services to smallholders, where other clients pay for additional services; revenue generated by direct payment for a service by the smallholder; paid service provision bundled into package, e.g. insurance coupled to credit, advisory to input supplies; the smallholder and/or other clients pay; and subsidized service were client pays a service subsidized by the government or other partner.
- Technological innovation in the areas of mobile connectivity and processing of satellite data facilitates upscaling. Furthermore, if the same transmission channels to reach the target audience can be used in all circumstances, then upscaling becomes much easier. Almost all G4AW projects make use of text messages and about half of the projects make use of apps, web portals and face-to-face contact (recorded in mobile devices or laptops).
- To reach smallholder farmers more effectively, there is a need for active advocacy and knowledge exchange to share success stories and learn from mistakes.

More information: <u>https://g4aw.spaceoffice.nl/en</u>

#### Market-led, User-owned ICT4Ag-enabled Information Service (MUIIS)

MUIIS is an initiative that uses satellite data to support extension and advisory services to farmers in Uganda. The project is funded by the G4AW Facility (see above) and is now in the second of its three years. It is being implemented by the Technical Centre for Agricultural and Rural Cooperation (CTA) together with six partners. The project is based on the need for timely and accurate information regarding crop management and climate risks and production demands in the country.

The MUIIS project takes a multi-stakeholder approach by recognising the unique expertise of each partner in the delivery of ICT-enabled extension services to farmers. MUIIS presents a complex solution that goes from collection of big data to the provision of information and knowledge, and in each of these components it has a dedicated partner with the necessary expertise. For instance, aWhere's role is to package the satellite data so that it is useful for farmers on the ground. The satellite data is processed on aWhere's server every day, and is immediately available on aWhere's application programming interface (API).

MUIIS represents another example of a public-private partnership. The project has private sector partners such as aWhere, EARS and eLEAF who bring their knowledge and creativity to the provision of value-added ICT-based services to the market, making the project more sustainable.

The project was designed based on farmers' needs. To ensure that needs were well captured, the project engaged from the early start the East African Farmers' Federation (EAFF). Furthermore, the selection of the value chains (maize, soya bean and sesame) as well as the information products to be offered (weather alerts, agronomic tips and financial services) was based on baseline studies.

Just like in Rwanda, the microclimate is also a main challenge in Uganda, which is why micro-level climate data is needed. The weather component is key to MUIIS; it provides farmers with weather alerts and based on this weather information, it advices on which agriculture practices they should engage. Instead of simply telling farmer if it will rain or not, the technology calculates how many millimetres of rainfall a specific farmer's crop needs and how much water over a longer period of time, being able to provide targeted advice to the farmer. Mr Benjamin Kwasi, programme manager at MUIIS, mentioned that it became clear that the model used was not able to give long term predictions for droughts as this is too complex, but that it focuses on short term forecasts, based on which weather alerts and advice are provided.

The services and products are based on the weather situation of the farmers' field. A detailed profile of each farmer is made and kept in the system. The partner Mercy Corps set up a mobile data collection tool called ONA that would make it possible to profile the farmers. MUIIS uses a model by which agents on the ground are being trained in mobile phone literacy and on how to use the application to do the profiling of farmers. Agents are engaged for the data collection and to show products to the farmers.

Once farmers have been profiled, their data is stored on the server and farmers can choose to subscribe to the MUIIS bundle service. This data is then shared with satellite data partners who are able to monitor what is happening in the farmers' fields. Farmers who subscribe to the service, receive directly an SMS with information and advice. The bundle also includes premium crop insurance.

Farmers pay 14,000 Ugandan shillings for the bundle. As mentioned by Mr Kwasi, a major challenge faced by MUISS is that the majority of farmers are not able to pay for the services, so the subscriptions have remained low. In the first season, only a hundred farmers paid for the service. MUIIS is thus trying to adapt the marketing model and pilot different strategies.

#### Key lessons learned:

- From the design stage, MUIIS invested much effort in building partnerships which are crucial for this initiative
- While the product is being subsidized, costing the farmer 14,000 Ugandan shillings for the bundle per acre, it is still not being purchased by farmers, either because it is not affordable or because they do not want to pay. The experience has proved difficult to convince a farmer to pay for advice or insurance as opposed to pay for tangibles, such as fertiliser, seed and chemicals.
- In view of low subscriptions, MUIIS had to adapt the business model in between. MUIIS is trying new strategies such as group subscriptions or looking for other resources, such as financial investors interested in accessing the farmers' data.
- While ICTs have the potential of transforming agriculture, there are still challenging aspects when it comes to initiatives for smallholder farmers. MUIIS initially thought the technological component would be simple as they had a strong team of technology experts, but then realized it was more complex since the solution had to be done in such a way that smallholder farmers could easily understand and use it.
- Understanding well the farmer and its specific location (through techniques such as profiling) is important for getting accurate and customized information to the farmer.
- The profiling data served to gather important insights, such as the fact that the majority of the farmers in Uganda have feature phones, not smartphones.
- The G4AW facility supports MUIIS for a period of 3 years, which is a good amount of time to develop well a product and deploy it to the field as well as to get feedback. Feedback is an important aspect of the product development cycle. It gives the partners in MUIIS the opportunity to discuss and assess what works and what does not work, ultimately helping improve the service.

More information available: <a href="http://muiis.cta.int/">http://muiis.cta.int/</a>

#### Kukua

Kukua is a startup that aims to leverage new weather station technology to provide accurate weather data and forecasts to smallholder farmers and other stakeholders in Africa. The weather stations are connected to the Internet, solar-powered and cost-effective. To date, Kukua has over 80 weather stations operating across six African countries, including Kenya, Uganda, Tanzania, Mozambique, Ghana and Nigeria. The technologies have been developed by SODAQ, the hardware partner of Kukua; and installed near cell towers in partnership with telecom tower operators.

Kukua specializes in the collection, consolidation and commercialization of data services. Weather data from the stations is collected real time in the Kukua cloud, and then weather forecasts are produced in partnership with the international private company Foreca, specialized in weather
services. Raw weather data is available on Kukua's dashboard and through their API. Main customers of this weather data include smallholder farmers and agriculture extension workers as well as researchers, renewable energy companies and insurance companies.

The business model involves the commercialization of data to companies with an interest in climate data. In Ghana, for instance, Kukua has been successful in selling data to companies from the cocoa industry. By earning a revenue directly from the companies, the services offered to farmers can be for free. Farmers receive weather information via text messages, which enables them to make informed decisions about when to plant, insure their crops, apply pesticides and fertilizers, harvest, and plant a different crop.

Kukua's interest is to have a network of stations that collect reliable localized data across the region, based on which new products and services can be created. In this regard, it wishes to collaborate with other initiatives in the region. It has, for instance, established a MoU with TAHMO with the interest of having more stations that are sustainable and well maintained, so that more data can be collected. Kukua asks TAHMO to put the data from their weather stations in Kukua's system, and in return shares revenues when the data is sold. This is possible given that Kukua's platform can integrate data from various sources. This same data is then sent to European Centre for Medium-Range Weather Forecasts (ECMWF) that is in charge of assimilating the data.

More information: <u>https://www.kukua.cc/</u>

## Box 5: UjuziKilimo

Kenya-based UjuziKilimo has developed a soil analysis platform that measures soil characteristics for assessing quality in farming use cases. Hardware elements of the solution include an electronic sensor placed in the ground, which alerts and gives farmers guidance, via SMS, on real-time soil conditions. The startup uses Big Data analytics to provide useful insights on farming trends and productivity based on the accurate data that is generated. UjuziKilimo uses the data to further customise farmer recommendations and make the advice more actionable.

More information: <u>http://www.ujuzikilimo.com/</u>

#### **Box 6: Illuminum Greenhouses**

Kenyan startup Illuminum Greenhouse develops innovative solutions for the agricultural sector. Its greenhouses use solar panels and sensors to control and maintain an optimal growing environment. The startup constructs affordable, modern greenhouses and installs automated drip irrigation kits for smallholder farmers by using locally available materials and solar-powered sensors. The iHub based startup embeds sensors in the soil that read how much moisture there is. When the sensors detect that water is needed they trigger an irrigation system which then provides the exact amount of water needed.

More information: <a href="https://illuminumgreenhouses.com/">https://illuminumgreenhouses.com/</a>

# **ANNEX 3: Project activities**

Below is a detailed review of the key pilot project activities:

### Phase One

## 1. Training on sensor data relay box assembly (3 November 2017)

University of Tokyo (UoT) staff provided training to Tumba College of Technology (TCT) graduates on the concept of IoT, assembly of the data relay box and software instalment. The assembled devices contained four sensors, including soil moisture sensors, temperature sensors, wind speed sensors and water depth sensors. On the first training, sixteen devices were assembled at TCT and two of them installed at Kawangire Weather station to see how they worked.



#### 2. Stakeholders' workshop in Kayonza (7-9 November 2017)

Following the training on Sensor Data Relay Box Assembly, a workshop with key stakeholders was held to gain a better understanding on IoT and meteorological application, do a site visit and discuss actual places for setting up sensors as well as discuss safety measures. The workshop was attended by representatives from MIDIMAR, RAB, REMA, RWFA, MINALOC, Kayonza District as well as sector agronomists, local leaders from selected areas, TCT graduates, JICA, Meteo technical staff, UoT and UNDP staff.



All stakeholders gathered to learn about the IoT concept and the use of microclimate data in agricultural planning and drought management as well as discuss needs felt by institutions and local leaders. During the workshop, participants discussed the technical constraints and opportunities of different sectors within Kayonza District to select the ones for the pilot project. Considering the climate and electricity conditions in sector offices, Murundi, Ndego and Rwinkwavu were selected as pilot sites.

Participants also discussed the climate information that is needed in Kayonza, pointing to information such as rainfall, temperature, wind, soil moisture, solar radiation, crop and livestock, and agricultural practices information. Another discussion was around the challenges and opportunities for information dissemination to the population. Main challenges included poor network coverage, no electricity, only one radio station, lack of equipment and lack of knowledge. Opportunities, on the other hand, included the availability of internet and BTs (Base-Station Transreceiver), decentralization of local governance, political will to promote ICT, an existing feedback mechanism (toll free number) and existing channels such as radio broadcast, TV, Newspaper, SMS, website, social media, emails and live shows.

During the workshop, TCT graduates, Meteo Rwanda technicians and engineers, local stakeholders and UNDP project staff went to the field to identify the actual site for the project and test the electricity stability and network coverage. For testing and comparison purposes the project installed two sensor boxes at Kawangire Meteorological station. This allowed to identify some technical issues to keep in mind for next stages.



#### 3. Field visit to Kayonza District (11-13 December 2017)

Based on the opportunities and challenges identified in the stakeholders' workshop, the technical team comprised with Meteo, UNDP, RWFA, RAB and MIDIMAR conducted a field work to design the pilot data collection system. On the first two days, the project team visited Murundi, Ndego and Rwinkwavu Sectors to conduct in-depth user interviews and to see the actual sensor set-up location. On the last day, based on the information collected on the field, participants discussed

recommendations and mapped the stakeholders to be engaged in the next project phase. A map of stakeholders can be found in the next section.

# 4. Assembly, set-up and maintenance of sensors (9-18 January 2018)

After bringing sensors from Japan, the University of Tokyo staff, UNDP representatives, Meteo technical staff and Tumba College of Technology (TCT) graduates travelled to TCT to reassemble the sensor boxes as well as discuss the problems the sensor boxes could potentially face and find solutions. For instance, Meteo presented the problem of batteries having no charge after midnight. Initially three boxes were assembled and were left at TCT to see if they presented any problem. On the next day, soldering for all the boxes was done, and it was agreed to set up the delay time to 15 minutes to avoid running out of battery. A new server run by WiredIn in Rwanda was introduced, where the data can be accessed.<sup>25</sup>



After the assembly, the sensors were set up in the three sites: Murundi, Ndego and Rwinkwavu, and sector officers received instructions on how to take care of the sensors, how to restart the devices in case the Wifi is off, and how to view the data. In Murundi, four sensor boxes were set up on the Wifi since the modem internet connection was not very good. In Rwinkwavu, the modem was working well with 3G internet; two sensor boxes were hence set up on the modem and the remaining two on the Wifi. In Ndego sector, the four sensor boxes were set up on the Wifi since the internet is 2G and is not very good.

<sup>&</sup>lt;sup>25</sup> The data can be accessed here: <u>http://bit.ly/KayonzaSensors</u> (Username: meteo; password: meteo1234)



Afterwards, a steering meeting was held with major stakeholders and the local leaders of Kayonza District to discuss and understand the progress of the project. In the framework of this meeting, a workshop was held for the sector officers and agronomists to clearly understand IoT project and how to take care of the sensors.

# 5. Design-a-thon for Climate (20-22 February 2018)

As the final stage, UNDP with Rwanda Meteorology Agency and the University of Tokyo conducted a Design-a-thon to convert the real time data that was being collected into usable and accessible information applications through a collective designing process. The Design-a-thon brought together young programmers and technology experts as well as national and local stakeholders.

The Design-a-thon workshop lasted three days. 18 teams made of 66 participants were introduced to the design challenges and were guided throughout the entire Design Thinking process to come up with ideas and prototypes of climate information applications that can accelerate effective planning and decision-making in water resource management, disaster risk reduction, agricultural productivity, and climate risk adaptation in vulnerable areas.



On the second day participants had the opportunity to do a field visit to Rwinkwavu Sector to see how the sensors work and talk to sector agronomists and smallholder farmers. They were able to get a better understanding of their users' needs and ask for feedback on the prototypes of their applications. On the third day participants worked on their final presentations and pitched for their proposed applications in front of a jury.



Six teams were selected to go to the next stage and work on developing a minimum viable product (MVP) for 20 days, under the guidance of an Application Development Manager. The participants' understanding of the issues faced by METEO Rwanda, RAB agronomists, and smallholder farmers was informed by numerous meetings and field visits. Since the beginning there was a constant updating of assumptions about how these issues would be addressed, and participants were flexible in modifying their projects.

Initially they knew there was a need to streamline the communication of weather predictions between METEO and farmers in drought-prone areas. This could have been achieved with a direct messaging platform for METEO to broadcast their predictions. However, during the field visit to Kayonza district they learned from farmers and agronomists about the need for advice and not weather predictions, information but not data. The RAB agronomists need to play a role in the information being sent to farmers, as weather information alone provides little actionable information. These agronomists should be able to make short and long-term recommendations, each of which utilizes weather information in a different way. For example, short-term advice would utilize rain forecasts and tell farmers not to lay fertilizer for the next few days. On the other hand, long-term advice would utilize seasonal forecasts and historical data in order to recommend which crops would bring the most yields as well as the timing of when to plant and harvest.

Speaking directly with METEO, the teams learned about how weather predictions are actually made. Using a combination of weather stations, regional satellite information, and mathematical modeling tools, meteorologists make regular predictions of up to one week. This information is then updated on METEO's website and shared with governmental and news agencies. However once it is released, METEO often has no way of knowing if their predictions are true. Since forecasts are given at a large-scale district level, many sub-regions within the district may experience vastly different conditions. This suggest that there is a feedback mechanism missing, which would allow the improvement of weather modeling tools and allow predictions to be made on the sector level.

Four out of six teams were interested in prediction dissemination and feedback between METEO/RAB and farmers, while the other two would focus on predictive weather models. However, the two teams interested in predictive weather models learned from meteorologists that building a weather prediction program is an extremely complicated endeavour, requiring expert knowledge of

fluid dynamics and immense computer processing capabilities. In response, one prediction team decided to concentrate on the prediction of particular indicators, rather than entire weather events. Their prediction of soil moisture would then be relevant to RAB agronomists who use these numbers to advise farmers when to plant their crops. The other prediction team moved instead to the development of an Application Programming Interface (API), after learning about the challenges of accessing weather data. Teams wanting to build applications on top of weather predictions and real-time information were unable to do so because there was no API in place previously.

Teams also learned more about Meteo's weather station infrastructure, which consists of a combination of automated and manual weather stations. These manual stations are manned by employees of the agency as well as "volunteer observers", who log recordings each day and send this information at the end of the month. There is however no way for METEO to verify the accuracy of these recordings. METEO suggested that teams develop an application to facilitate volunteer observer recordings with geo-location mechanisms to verify that the recording was taken in the correct place. A number of teams took up this task, integrating an observer form into their existing smartphone applications.

In summary, participants worked on the following solutions:

- SMS and USSD application to send climate information to farmers
- Android applications for Sector Agronomists to have better access to data and to communicate directly with farmers
- Prediction of particular indicators (soil moisture) relevant to RAB agronomists who use these to advise farmers when to plan their crops
- API to access climate data from Meteo Rwanda

The final application prototypes were then presented at the Partnership Workshop. Applications were judged by how well they met the stakeholder needs and the quality of the code and software architecture. The winning prototypes include:

# Kubero - 1st place

Kubero proposed building two applications: one Android app to be used by RAB (agronomists) and a USSD application primarily for the farmers to query weather data. The android application would help RAB add value to the predicted data by recommending farmers what to do based on the weather data as well as allowing agronomists to communicate directly with the farmers through SMS. This application also includes a feature to help Meteo volunteers submit weather data to Meteo in a digital and ready to use format. The USSD application instead would be used by farmers to receive weather information and recommendations from RAB as well as to provide feedback to Meteo on the accuracy of the predictions, helping improve Meteo's prediction models.

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#### Raptors (Siphon App) - 2nd place

Raptors' prototype is a messaging API that triggers SMS's to be sent to the farmers once a certain condition exceeds the threshold and allows experts to send out recommendations to the farmers and get back feedback on the accuracy of the information provided. The platform gathers data from the Sensor API and the Weather API which provide information about rainfall, humidity, winds and temperature. If any of this conditions exceeds the threshold, automated disaster alerts will be sent directly to the farmers to be warned. The platform allow farmers to register from their phones directly and be grouped according to the sector they are in. Meteo representatives can directly input their recommendations so that they can be broadcasted to farmers as per the sector. Farmers can also give feedback on the accuracy of the information they receive, helping improve the accuracy of the models used by Meteo for the predictions. The app includes a farmer reward system for giving accuracy feedback. Through SMS, farmers can also communicate with a representative of Meteo or RAB to get customized recommendations on the kinds of crops to grow.

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# 5aaf21f7764c2140ac43c9ad	Timestamp Mon Mar 19 2018 04:35:35 GMT+0200 (South Africa Standard Time)	Rwinkwavu	We are expecting some strong winds tool and some drizzling before noon
# 5aaf21f7764c2140ac43c9ad 5ab10961ea54af2ba419722d	Timestamp Mon Mar 19 2018 04:35:35 GMT+0200 (South Africa Standard Time) Tue Mar 20 2018 15:15:13 GMT+0200 (South Africa Standard Time)	Rwinkwavu Murundi	We are expecting some strong winds toda and some drizzling before noon This is from Meteo to Agronomist

Send out recommendations to far	mers and display previous broadcaste	d recomme	ndations per region!	
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#### Tymlee - Innovation award

Tymlee's prototype is an Application Programming Interface (API) that will interface with all applications that need data from Meteo and also receive feedback from other end users. Their solution focuses on facilitating the process of acquiring data from Meteo, which will enable developers to build innovative weather applications. In addition, the team developed an application for the people in the manual weather stations to ensure they submit recordings when they are at the station by taking a picture of the measuring device. The readings are then sent to Meteo via the API.

To give Meteo complete control over who they choose to grant access to their data, , the solution uses API keys which are given to users upon request.

#### Meteo API

This is an API prototype for Meteo Rwanda

Request/requests : Operations related Request of Tokens	Show/Hide   List Operations   Expand Operations
POST /Request/requests/	Creates a new user token request
Historical/requests : Operations related Historical Data	Show/Hide   List Operations   Expand Operations
POST /Historical/requests/	
administrator/request : Operations related to the Administration	Show/Hide   List Operations   Expand Operations
POST /administrator/request/	Creates a internal user
ددت /administrator/request/apicalls	Get Api Calls
PUT /administrator/request/approvetoken/{email}	Approve Token Request
GET /administrator/request/customers	Get Customers
GET /administrator/request/tokenrequests	Get Tokens
observer/login : Operations related to Observer	Show/Hide List Operations Expand Operations
POST /observer/login/	
forecast/requests : Operations related Forecast Data	Show/Hide   List Operations   Expand Operations
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#### Farmate - Inspirational award

Farmate team worked on three application prototypes: a web-based application, a USSD based application and an android based application. Farmate web-based application analyzes climate data from sensor network API and provides useful information to the farmers. The analysis consists of sourcing historical data from sensors API and building a forecasting model. Additionally, the app allows volunteer observers to submit feedback temperature and rainfall data and it detects their geographical locations. The USSD based application serves as a daily communication channel for volunteer observers from the manual stations to send rainfall, temperature and wind data to METEO Rwanda. The android based application is designed for three users: farmers (or anyone else); Meteo volunteer observer and Meteo agent. It helps all users get daily weather information according to their location, read latest announcements as well as send feedback to Meteo.





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#### Fortuna (Mfasha app) - Inspirational award

Mfasha app is a web service and android application that allows agronomists to select their location and access weather information as per their location as well as to save farmers' contact information. Agronomists can then communicate with the farmers either via a call or SMS function and can also share information via social network. The app also includes a feedback functionality.

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# 6. Partnership Workshop and Report (20 March 2018)

A partnership workshop was conducted to work on ideas for scale up of the IoT project after the pilot project ends. The workshop lasted one day, where the draft of the Business Plan Report and the further developed prototypes from the app teams were presented. Stakeholders at the local and national level, from the technology, policy, and science sides were invited to contribute their ideas and opinions. Impact Hub facilitated these stakeholders to collectively think about the challenges and opportunities of scaling up. Methodologies such as the World Cafe were used to encourage the collection of diverse viewpoints and ideas.





## Main outcomes of the partnership workshop include:

## Data collection

- There are still many possible pathways to go forward, particularly in choosing WMO standard IoT weather stations vs smaller, less-expensive IoT sensors tailored for a specific application, such as flood detection. The pathways here will depend on testing out assumptions with stakeholders and their institutional needs during phase 2.
- Meteo forecasting requires WMO standard equipment, which can be 3 times more expensive than non-compliant sensors. If non-compliant sensors are used for research and development, there needs to be a plan to move toward WMO standards in the future. Another option is that other stakeholders could be responsible for non-compliant sensors, such as MIDIMAR managing flood detection sensors and combining that with standardized rainfall data from Meteo.

# Data assimilation

- All data that Meteo collects needs to go through some quality control checks before it is entered in the database. This would include new data from sensors.
- Much of the data assimilation from different models and data sources in Meteo is still done manually, and there is potential for tools that could help forecasters do this more readily.
- Much of the data entry is still done manually as well, and it could be helpful to develop the API to accept new data sources to reduce manual work and errors, and make the system more scalable for adding new data sources in the future.

# Data distribution

- A fully developed API opens up many possibilities for using Meteo data in new ways.
- However, there is concern that data will be sold in products without giving credit to Meteo when Meteo provides the data for free.
- Another concern is that data will be misinterpreted. Meteo is the only organization that is
  allowed to make official forecasts. Thus in-depth discussions are required to clearly define
  who can access the API for what purpose, and these rules can be applied when organizations
  are granted API access.

• Maproom is a good example of opening information instead of data, further discussions are needed to clearly define which information will be accessible through the API.

## Data usage

- There are different pathways to go forward. The usage is informed by the data collected and the technologies used. Climate information can be used for better agriculture planning, Disaster Risk Management and early warning systems, water management and irrigation planning, transport and urban planning, among others.
- Any new initiative that aims to improve the provision of climate information services should be within the National Framework for Climate Services, led by Meteo.
- The provision of climate information services should come primarily from government institutions. The private sector, particularly telecom companies, may be engaged to help Meteo or another national institution meet its mandate.
- Necessary climate information services include information packaged according to the specific needs of each sector and target group, good and precise forecasts, advice, and insurance (for farmers). The services should be provided in such a way that they allow the collection of feedback from the users.

## Phase Two

This second phase of the project focused on deepening the learnings from Phase One.

### 1. Development and testing of Phase One solutions (March – July 2018)

Winning solutions of Phase I were further developed and tested. The farmers' application was tested with agronomists and farmers, and the feedback collected was incorporated. The application aims to disseminate information with suggestions from agronomists to farmers for better agricultural planning. The application is ready to be piloted before a mass rollout. The volunteer observer application was also further developed and tested and is ready for implementation. This application will allow volunteer observers to digitize the recording of data at Meteo Rwanda manual stations. The other solution, the API, was further developed and installed on a server in Meteo Rwanda Headquarters, with a publicly facing IP address. A training session was conducted for Meteo staff to know how to maintain the application, ensuring that the server is running and connected, and that it has all the right permissions to access to Meteo's database. The API will improve access to Meteo Rwanda data and allow the development of new climate information applications/products.

#### 2. Roundtable discussion (June 2018)

As part of this second phase, a roundtable discussion was held with stakeholders, including Meteo Rwanda, MIDIMAR, RAB and WFP, to identify key challenges regarding climate information for Early Warning in the country. The discussions allowed for a clear understanding of the flow of climate information and helped identify and document the gaps in setting up an early warning system. The gaps identified can be broadly categorized in the following (more details on the gaps and needs identified can be found in section 2.2):

- **Collection of climate data:** Climate data is critical for disaster risk management, early warning and rapid response to disaster. However, there are challenges associated to the collection of localized data in a timely and accurate manner.
- Integration of climate data: Data collected by Meteo Rwanda needs to be integrated with other relevant data (such as MIDIMAR database of disasters and disaster risk profiles) to improve the capacities to prepare for disasters.
- Dissemination of climate data: Finally, there are challenges in the flow of communication between agencies involved in disaster preparedness, including Meteo Rwanda and MIDIMAR, and between agencies and the end-users. There is a need for mechanisms and tools to improve the dissemination of weather information and Early Warnings to local communities in order to reduce their vulnerability to disasters.

## 3. Hackathon for Climate Early Warning and IoT trainings (18 – 24 July 2018)

Having identified key challenges in the Roundtable Discussion, Meteo Rwanda and UNDP organized the five days Hackathon for Climate Early Warning in Kayonza District, bringing together 10 teams made up of 33 participants. The teams were introduced to design thinking and then focused on prototyping and testing solutions to the challenges presented. Throughout the five days, they talked to government stakeholders to gain more insights into the gaps and needs as well as received technical guidance from various mentors. The Hackathon emphasized the relevance of collaborating to co-create relevant solutions as opposed to competing, and created spaces for participants to share their work and ideas.

On the side of the hackathon event, there were a series of trainings on the basics of IoT technologies, IoT weather stations and IoT for Early Warning. The trainings were attended by key project stakeholders such as Meteo Rwanda, MIDIMAR and RAB staff, and Tumba College of Technology graduates. Additionally, they were optional for Hackathon participants interested in deepening their knowledge in IoT.

As part of the IoT training and in the framework of the hackathon, an analysis was also conducted on the hardware and data of the sensors installed during Phase One of the project. The sensor analysis led to a few key findings related to the durability and accuracy of the IoT sensors. Firstly, the data shows that the devices from Rwinkwavu were only transmitting information for about one month. This is attributable to a power failure caused by either the solar panel breaking off or becoming so dirty that is ceases to function. Within the month the IoT sensors were transmitting, there is a slight difference between the IoT data and Meteo's own readings. Comparing temperature, it is clear that while most of the time the IoT sensors matches Meteo Rwanda, they consistently reach higher peaks than the WMO standardized Meteo readings. This could be attributed to a need for calibration or improper sensor placement; at Rwinkwavu we discovered that the temperature sensor had been placed inside a metal pole. While quality sensors and regular calibration are key, it is clear that the IoT sensor project cannot function without the sector-level stations' help in maintenance and diagnostics. At the end of the Hackathon event, participating teams pitched their solutions to a jury. The grand winners included:

## STES

Sensors to collect soil moisture data placed at different depth levels and a dashboard to monitor if the sensors are working or not. Their solution proposes the use of radio mesh network to send data of sensors to base stations. The benefits of the system are that it is low-cost, it can work in remote areas, collects data automatically, is easy to maintain and can be calibrated through comparison which is cost effective. The collection of soil moisture data can help predict landslides.



#### EcoDev

A solution that aims to improve flash flood early warning system using Machine Learning techniques, with the option to apply methods to other natural disaster later on. A web platform will use a machine learning algorithm to help MIDIMAR to quickly identify at risk areas, visualize the areas on the map and communicate the information to concerned officers.



#### **Binary Earth**

B.E AWARE platform visualizes Meteo weather alerts and MIDIMAR disaster information together in context. Using Meteo weather alerts and GIS, the platform produces a live map of disaster areas. The

platform further produces dynamic historical disasters maps to help in preparedness. It also incorporates channels to help MIDIMAR automatically communicate to officials and end users.



# Other winning solutions included:

#### Silver Prizes

#### **Dream Team**

Platform to automate the communication between Meteo Rwanda and MIDIMAR, and between MIDIMAR and end users. The solution includes SMS and Android applications to send alerts to the public, an Android application for officials to send feedback to MIDIMAR and a USSD application for the public to consult information/ send back feedback.



## **Hugs for Bugs**

Online platform to automate the flow of communication between Meteo Rwanda and MIDIMAR. It includes features by which MIDIMAR can notify end users via SMS and email, as well as receive updates and disaster feedback from the sector level via automated phone calls.

#### Clinfonot

Dashboard and mobile application to automate the flow of communication between METEO and MIDIMAR, and between MIDIMAR and end users. The solution allows for feedback from MIDIMAR to Meteo as well as from MIDIMAR district and sector level officials and the population in general back to MIDIMAR.



Wiconn

Platform to automate the flow of communication between Meteo and MIDIMAR and from MIDIMAR to end users, as well as an SMS-triggered siren. The solution also includes a USSD application for the population to consult forecasts and other climate information.

## **Inspirational Prizes**

## HubTz

The solution included the use of cost-effective soil moisture sensors to collect data. It proposed a local network expansion at the cell level transmitted through radio frequency as well as a dashboard to view the data collected.

## Farmate

Web and mobile application to organize and visualize Meteo Rwanda weather alerts together with MIDIMAR disaster risk profiles. It includes the option to send out SMS alerts to MIDIMAR officials at the district and sector levels.

## Fortuna

Mobile, web and desktop application to automate the flow of information from Meteo to MIDIMAR/RAB and from MIDIMAR/RAB to the end users (farmers and vulnerable population).

## Summarized version of proposed solutions (to be scaled up in Phase 3):

- Low-cost sensors to collect soil moisture data and a dashboard to monitor sensors data
- Platform using machine learning algorithm to help MIDIMAR to quickly identify at risk areas, visualize the areas on the map and communicate the information to concerned officers
- Platform to visualize disaster risk areas by contextualizing Meteo weather forecasts with MIDIMAR disaster risk profiles
- Platform to automate the flow of communication between Meteo and MIDIMAR, and between MIDIMAR and the vulnerable population (end users)
- Android, SMS and USSD applications as well as sirens to disseminate early warning information to the population

# 4. Partnership workshop (24 July 2018)

A partnership workshop was conducted to review the project so far and discuss ideas for scale up of the IoT for Climate project after the pilot phase. The workshop lasted half day, where the overview of the project and key findings were presented. Furthermore, stakeholders discussed possible ways of scaling up the project. The discussion outcomes can be found in **chapter 3.2**.

#### 5. Business Plan Report

As a final activity for the pilot IoT project, this business plan report was written to document the process, achievements and lessons learned of the pilot project and identify challenges, opportunities and strategies for scaling up the initiative to a national level and potentially to Sub-Saharan Africa.