FRONTIER TECH HUB

IoT Sensors for Social Impact: Executive Summary

I Vickers & P Vishwanath

PHOTO CREDIT: LAHORE UNIVERSITY OF MANAGEMENT SCIENCES (LUMS)
IoT sensors deployed in Pakistan as part of the Frontier Technologies Early Warning Forest Fire Detection System pilot

IOT Sensors for Social Impact: Executive Summary

April, 2023.

This material has been funded by UK aid from the UK government as a part of the Ideas to Impact Programme; however, the views expressed do not necessarily reflect the UK government's official policies, nor those of any of the individuals and organisations referred to in the report.

We would like to thank the following organisations for their participation in Frontier Technologies pilots and the research for this report: eWATER Services, Regen Organics (formerly known as Sanergy), World Wildlife Fund, Lahore University of Management Sciences, International Centre of Insect Physiology and Ecology, Youth Innovation Labs, Zihanga Ptd. Ltd. The views expressed in this report are those of the Frontier Technologies Hub, and do not necessarily reflect the official views or positions of the organisations who participated in the research.

FRONTIER TECH HUB

UKaid from the British people

Introduction

Scope of this report

Since 2016 the Frontier Technologies programme has supported 10 pilots to test the potential for IoT sensor based solutions to deliver social, environmental or humanitarian impact across a range of sectors and use cases.

This report is concerned with sharing findings from Frontier Technologies pilots on what's needed to effectively test and scale IoT sensor solutions for social, environmental or humanitarian impact. Where relevant, it also shares insights from wider studies and pilots, including other FCDO investments. The report aims to primarily share insights from the perspectives of those involved in directly delivering early stage innovation projects. It shares insights on the types of solutions that have been tested (including details on 'what worked') in relation to three key use cases for IoT. It also seeks to share insights from pilots on the barriers and enablers to successfully testing and scaling IoT sensor solutions, and reflections from the Frontier Technologies Hub, on where the 'frontier' is, in terms of developing, testing and scaling IoT sensor solutions for impact.

What are IoT sensors?

For the purpose of this report we define Internet of Things (IoT) sensors as sensing devices which are able to take an input from the physical environment and convert this input into data (through in-built microprocessors) - such as a temperature reading. This data is then communicated over the internet (or other network), to other devices within their network, in ways that can trigger automated responses by other smart devices, and / or inform stakeholders to make more effective decisions.

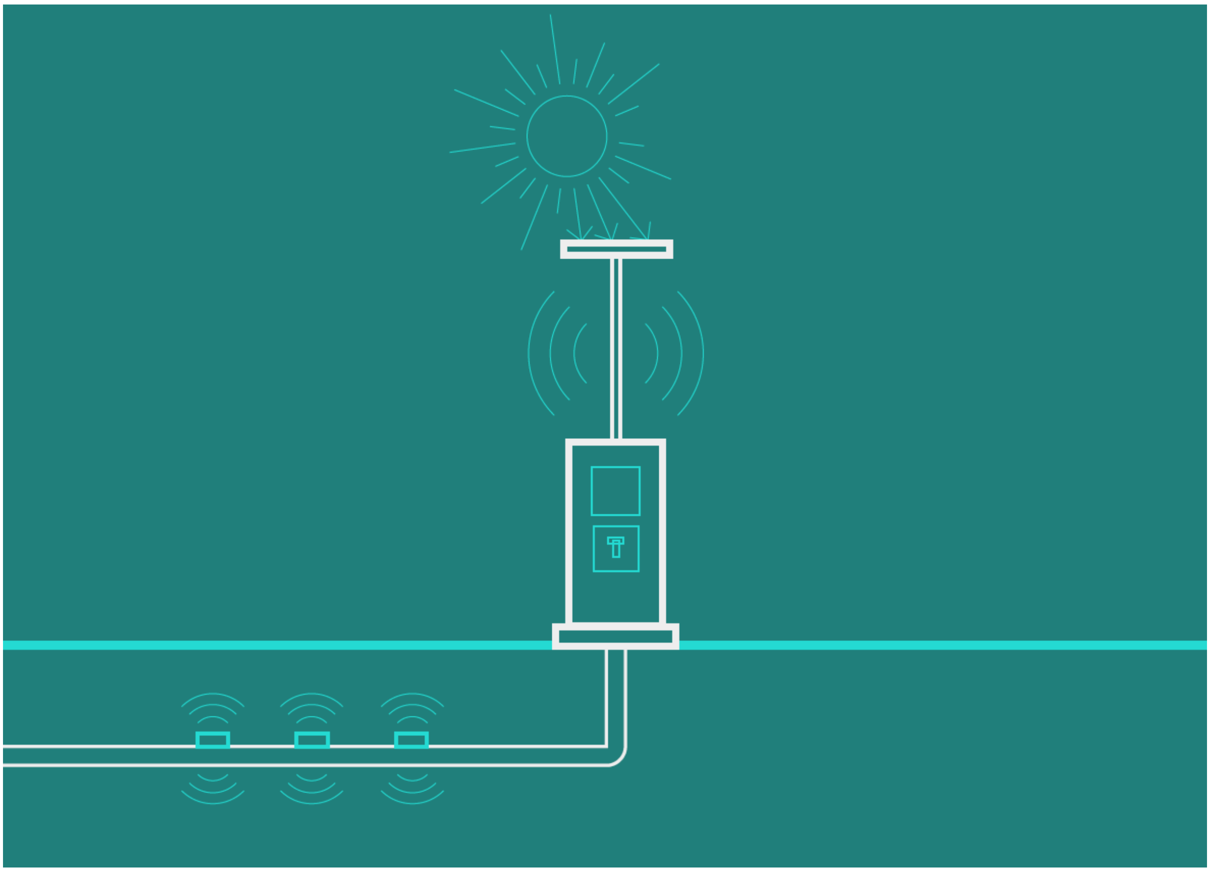
Recent technical trends have seen a number of developments that could potentially support the proliferation of IoT sensors for social, environmental and humanitarian impact. This includes the emergence of lower cost and durable devices, as well as the deployment of Low Power Wide Area Networks, by mobile operators in many markets, into which devices can connect with lower power consumption - which supports the longevity and therefore viability of devices.[1]

[1] GSMA, 2023

Use cases where IoT sensors have been used for Social Impact

Across Frontier Technologies pilots there have been three key use cases for which IoT sensors have been piloted for impact. Below we have outlined key findings in relation to each use case, in terms of the different ways that sensors can be used to meet end user needs.

1. Improving access to clean water and sanitation



GRAPHIC CREDIT: Dave Thomas - Picnic Films

Applications of IoT sensors for increasing access to clean water

Over the last decade, a number of different projects have implemented IoT sensors in order to improve access to reliable water. A key problem that these solutions have aimed to fix, is the unreliability of existing water infrastructure, particularly in rural areas. It was estimated a decade ago that globally one in three handpumps in rural areas were broken.[2]

[2] Rural Water Supply Network, 2010

In 2016 the Frontier Technologies eWATER pilot installed IoT sensors within solar powered water systems in rural Tanzania. Sensors for monitoring the pressure of water in tanks and flow of water from individual taps were installed, and data from these sensors was transmitted over the internet and shared with engineers in eWATER's Smart Maintenance Teams. Through monitoring patterns in water flow and volume, engineers were able to identify issues and breakages in the WASH system, and respond - increasing the uptime of water taps to 99% (up from around 66%). Collectively, sensors were able to provide engineers with a joined-up picture of the health of individual WASH systems, with data displayed on a Geographic Information System. This has enabled eWATER to better identify trends and patterns in both usage and issues, in ways which can inform smarter decisions on managing WASH assets.

In order to sustain the solution, eWATER implemented and tested a business model whereby end-users pay for water via cash or mobile money. Mobile money can be put onto their own account, or this innovative use of technology also allows family members to load credit onto anyone's individual tag from anywhere in the world. Through implementing this model, eWATER have delivered a service based approach to water provision - whereby the money collected for water consumption is in turn used to pay for engineers time and any other activities eWATER needs to conduct in order to ensure water is available at the point of need. Over time eWATER has been able to demonstrate the longer term potential for this service based approach to offer a sustainable economic route to scale.

PHOTO CREDIT: eWATER
An eWATER Smart Tap in use in Endanachan Tanzania. By holding a pre-paid NFC tag to the tap, water flow is initiated. Water flow sensors then determine consumption usage, and the amount to be debited from the users account

Other projects implementing IoT water flow sensors have demonstrated their potential to combat the issue of non-revenue water (this includes water lost through leakages, or inaccurate meters before governments can collect revenue). Smart City Taps, a solution supported by UKAID via grants to the GSMA and GIF, combines smart water meters with a digital solution where customers can pay for their water with mobile money. In the case of the GSMA grant, CityTaps helped improve revenue collection by 100% in the part of the network where smart taps were deployed.[3]

In addition to improving the availability of water at taps and hand pumps, sensors are also increasingly being used to improve the quality of water in WASH systems. Traditionally water quality sensing technologies have suffered from long operation times (e.g. requirements to wait for samples to be tested in a laboratory) and high costs. However, a number of recent studies have demonstrated breakthroughs in water quality sensing - where sensors show potential for real time and continuous monitoring of water quality across a range of parameters.[4][5]

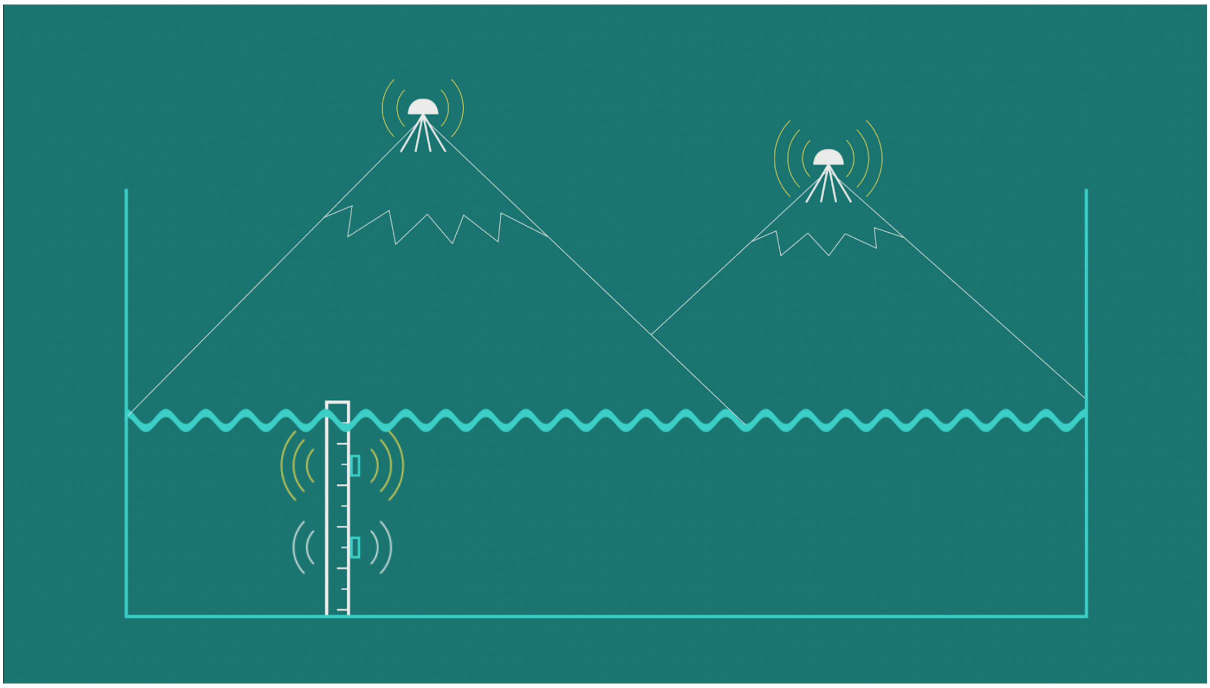
To what extent have IoT solutions been scaled for impact?

In addition to eWATER, a number of different projects have now demonstrated the effectiveness of water flow sensors, alongside service based business models, as viable routes to sustainably increasing access to water.[6][7] More recently, studies have also begun to demonstrate the potential for water quality sensors to unlock impact through providing real time data and insights on water quality.

However, despite these successes, remote monitoring of rural WASH systems through IoT sensors has yet to be taken up at significant scale in contexts where it is most needed.[8] As the eWater pilot and other projects have identified, outstanding barriers include the need for key stakeholder buy-in (such as local governments, who may continue to have a preference for supporting community, rather than service based models for WASH management), as well as high upfront costs to procure and install sensor technologies.

[3] GSMA, 2021
[4] Vargas et al, 2020
[5] Kavitha et al, 2021
[6] Smith School Water Programme, 2014
[7] Nagel et a., 2015
[8] Thomson, 2020

2. Disaster Risk Management - Natural Hazards



GRAPHIC CREDIT: Dave Thomas - Picnic Films

Applications of IoT sensors for Disaster Risk Management

Through providing stakeholders with access to precise, comprehensive and real-time data on changes in the physical environment, IoT sensors can play a critical role in supporting disaster risk management. This includes decision making in relation to the response to a natural hazard, as well as decision making to prevent, mitigate and better prepare for natural hazards.

Through the Frontier Technologies Early Warning Forest Fire Detection System pilot in Pakistan, the World Wildlife Fund (WWF) and Lahore University of Management Sciences (LUMS) are working together to deploy IoT sensors capable of detecting and alerting Forest Department stakeholders and community members to the presence and location of fires. The pilot is currently installing an IoT sensor network to collect data on temperature, humidity, CO2 and carbon monoxide, in order to provide early detection of fires. Alongside sensors, they have also installed cameras, each connected to individual AI modules, which are able to process images and visually detect the presence of a fire. As the pilot progresses, it seeks to explore whether these connected devices can provide the local forest department and local communities with the real time information needed to react to fires and trigger early warning systems. Due to the Internet of Things, there's potential to implement automated warnings - such as SMS notifications to affected community members, or the sounding of sirens.

PHOTO CREDIT: LUMS
IoT sensors were deployed in northern Pakistan as part of the Frontier Technologies Early Warning Forest Fire Detection System pilot

As well as supporting early warning, IoT sensors can also help inform the ongoing response to a disaster, by providing stakeholders with up to date information on the location and severity of an incident. Though the sensors are stationary, based on the GPS coordinates of the sensors, stakeholders can be informed of the location of the fire. The pilot has also begun to embed additional functionality that supports stakeholders to anticipate how the forest fire is going to develop. Through using sensor data, alongside remote sensing data, data on vegetation, weather data (e.g. wind direction), and AI, the LUMS team are currently building a fire spread predictive model - which is capable of providing visualisations of where a fire is likely to spread next as well as visualisations of fire "hot spots" (where fires are most likely to occur and the likelihood of occurrence). The intention is to provide the forest department and emergency services stakeholders with information to support decisions on how to safely tackle forest fires to preserve the environment and human life.

PHOTO CREDIT: LUMS
A camera installed in Pakistan as part of the Frontier Technologies Early Warning Forest Fire Detection System pilot. The camera is connected to individual AI modules, which is able to process images and visually detect the presence of a fire.

In addition to supporting stakeholders to respond to natural disasters, IoT sensors have also been deployed to generate data to help stakeholders understand the likelihood, risks and potential impacts of different natural hazards, before they occur. Over time, sensor data can be modelled and used to identify the areas at greatest risk from hazards. By combining and analysing environmental data with demographic, vulnerability and economic data, models can identify the areas where a potential disaster is likely to have the greatest impact in terms of affecting the most people or vulnerable groups who may have less resilience, or causing greatest damage to property and economies. This information can support stakeholders to make smarter decisions on how best to mitigate the impact of disasters, including decisions based on the cost-benefit analysis of different intervention options.[9]

In Nepal, Youth Innovation Lab are working on a Frontier Technologies pilot aimed at informing their next iterations to the Building Information Platform Against Disaster (BIPAD) platform. This is a platform that is owned by National Disaster Risk Reduction and Management Authority (NDRRMA), and provides Disaster Risk Management stakeholders (e.g. local governments, humanitarian agencies, NGOs) with real time and historical information on changes in the environment, as well as natural disasters and their impact. The platform is informed by a wide range of data collected from all over Nepal through a range of methods, including the use of internet enabled sensors monitoring changes to the environment related to flooding, forest fires and seismic activity. The BIPAD portal incorporates socio-economic data alongside sensor data, and provides policy makers with risk profile data on different regions, and the damage and loss that has been experienced by communities over time. In doing so, it aims to support more effective risk reduction interventions.

PHOTO CREDIT: NISHANT GURUNG
A water level sensor installed in Chisapani, Nepal. Data on water level readings are populated on the BIPAD platform.

At the frontier of technical solutions which use sensor data to inform natural hazard prevention and mitigation, are solutions which use AI to predict where a natural hazard will happen next, based on detailed analysis of large amounts of historical data, and on the trends and patterns in data which lead to natural hazards.

[9] Ruckelshaus et al, (2020)

Recently, studies have demonstrated the ability for AI based models to react to real time data and predict the likelihood of a river flood happening, to within a 95% accuracy.[10] What makes AI based solutions particularly exceptional, is the ability to identify trends and patterns in data that might not otherwise have been observed using previous data analysis approaches. Indeed, one model that has recently been developed in Nepal was able to identify the causal relationship between different 'cascading hazards', whereby risk factors that lead to a single hazard, can also be used to predict the advent of a second natural hazard, which will be triggered by the first hazard.[11] Theoretically, once more is understood about the relationships between cascading hazards, it should be possible to build solutions capable of not only predicting a single hazard, but predicting the cascading impact of that hazard, in a way that can inform smarter risk mitigation measures.

To what extent have IoT solutions been scaled for impact?

While IoT sensors show strong potential for supporting disaster risk management, they have yet to be significantly scaled within the global south. Many applications of sensors, and particularly those applications which involve using sensor data with AI solutions to support predictive modelling, remain at a proof of concept stage, and have yet to be scaled for impact.

The cost of devices remains a barrier to scale, and ongoing maintenance of sensors is needed in order for sensors to continue to provide data for decision making. It is worth noting that in the photo shared above of a water level sensor in Chisapani Nepal, the sensor in question was in fact broken when we visited, and manual data readings and data entry was conducted in order to populate the BIPAD portal. This points to the need to find sustainable models for funding and implementing technology, so that the benefits of improved information for disaster risk management can be resealed.

[10] Bouloulard, 2022

[11] Talchabedal et al, 2022

3. Improving agricultural productivity for smallholder farmers

GRAPHIC CREDIT: Bethan Thomas

Smallholder farmers make up 90% of farmers worldwide, yet suffer from lower productivity, increased vulnerability to shocks (e.g. extreme weather events) and often lack access to agricultural inputs, credits and markets.[12]

While not widespread, there are emerging examples where IoT sensors have been deployed to support precision farming for smallholder farmers. This is a practice where sensors are used to generate data on 'what works', which in turn is used alongside real time data to inform real-time decisions to optimise farming processes, inputs and growth conditions, to deliver benefits such as improved yields, environmental sustainability and reduced costs.

The Frontier Technologies Optimal Insect Protein Production pilot has begun testing an approach for using smart sensors to support precision farming, and optimise agricultural practices amongst smallholder farmers in rural Kenya. Led by Regen Organics (formerly known as Sanergy) and the International Centre of Insect Physiology and Ecology in Kenya, the pilot is currently exploring how sensors might be used to increase yields of black soldier fly (BSF) larvae, which is used in animal feed.

Working directly with smallholder farmers, the pilot has used sensors capable of monitoring a range of parameters (temperature, light, humidity, PH / moisture content of the substrate, ammonia / CO2 levels in the air), and aims to understand, via analysis of sensor data, what combination of parameters lead to increased yields of BSF larvae - so that a solution can be developed which provides farmers with data and tailored recommendations, on what changes they need to make to better optimise production. The longer term goal of the pilot is to conduct further work to identify what's needed to encourage farmers to adopt

[12] UNDP, 2021

the solution and achieve scale. This includes identifying what additional support farmers need to effectively implement the solution.

While the pilot is still at an early stage, farmers involved have already identified the benefits of sensors in helping them to optimise their processes. As Nicholas Ndekei, Chief Executive Officer at Zihanga LTD told us;

"Before we used to hatch our eggs in the traditional methods and would lose up to 40% of our production. The IoT forces you to quantify more things, and forces you to know what you need to do and how to do it. We saw an increase, we're getting 90% of production."

PHOTO CREDIT: ZIHANGA LTD
Photo 1: Sensors deployed at Zihanga Ltd, a small-scale BSF farm in the outskirts of Nairobi city.
Photo 2: Dried BSF Larvae as an end product of organic waste valorization.

These findings align with those of wider studies on the potential for smart farming amongst smallholders in LMICs, which also report benefits such as shorter production cycles, reduced costs, lower use of inputs (including scarce resources like water), higher yields and fewer losses to crops from pests and disease.[13]

Beyond Frontier Technologies pilots, there are a number of other IoT solutions which have been used to support smallholder farmers to increase agricultural productivity. A major example is the use of IoT sensors alongside smart irrigation systems - which can be triggered automatically, or manually in response to sensor readings on changes to environmental conditions such as soil moisture. In addition soil monitoring

[13] GSMA, 2022

sensors have also been used by solutions which help farmers to optimise fertiliser use, and avoid degradation of soil quality - such as the Soil Health Cards solution in India.[14]

In pastoral farming, there have been some limited implementations of IoT sensors to help smallholder farmers implement smarter livestock management - including using sensors to detect diseases immediately in order to support a faster response.[15] In aquaculture, IoT sensors have been used by smallholder farmers to optimise the feed provided to their fish, such as the eFishery solution in Indonesia, which uses sensors to detect the appetite of fish and shrimp, as well as IoT automatic feeders, to provide fish with the optimal amount of food.[16] Sensors have also been used by smallholder aquaculture farmers to monitor water conditions in fish tanks, and in hydroponics farms to monitor and optimise environmental conditions.[17]

To what extent have IoT solutions been scaled for impact?

While there has been a growth in the use of IoT sensors in farming globally, when it comes to smallholder farmers in the Global South, IoT smart sensors have yet to scale significantly. This is the case for smart crop management and livestock solutions, although there are some examples where aquaculture solutions have attracted 10,000 or more users, each paying monthly usage fees.[18] Within LMIC markets, there are few examples of IoT sensor solution providers actually developing and marketing solutions specifically for smallholder farmers.

For smallholder farmers, key barriers remain which inhibit their ability to adopt and benefit from solutions. Barriers include challenges around ease of use, digital literacy, cost of devices, costs of connectivity, and lack of mobile and IoT coverage, as well as gender barriers to accessing smart farming solutions.

[14] UNDP, 2021
[15] GSMA, 2022
[16] GSMA, 2022
[17] Antony, 2020
[18] GSMA, 2022

Cross-cutting findings - enablers, barriers and the frontier for implementing IoT sensors for impact

Across the three core use cases explored through Frontier Technologies pilots, there are common barriers inhibiting the effective scaling of IoT sensor based innovations, as well as common enablers. Below we have presented a summary of these findings, as well as details on the key 'frontier' areas of opportunity, where our research indicates further work should be carried out, in order to unlock opportunities for scaling IoT sensors and further explore emerging solutions for deploying sensors for impact.

What are the common barriers to testing and scaling IoT sensor technologies for impact?

- Even with significant advances in sensor technologies **durability and resilience of devices** has surfaced as a challenge across Frontier Technologies pilots, especially those that require sensors to work in harsh environmental conditions.
- Although the price of sensors have significantly dropped over the last 5-10 years, the **cost of devices** and other materials required for the implementation of solutions continues to be a barrier for both IoT implementers as well as communities and end users. Across different sectors high upfront capital costs can stall the implementation of solutions, even where they demonstrate potential to deliver longer term cost-savings.
- **Maintenance of sensors** is critical for sustainable scale, but also presents a challenge - particularly for projects which leverage sensor data, without directly implementing sensors themselves (e.g. Frontier Technologies pilot to support the BIPAD portal). Maintenance is especially challenging in cases where projects have installed sensors, but haven't developed sustainable models for maintaining sensors - such as projects which advocated for community based management, without making provisions for how communities would continue to fund and maintain sensors.
- **Limited interoperability of data sets and devices** can be a barrier to any projects looking to join up large volumes of sensor data in order to generate insights and trends to support decision making. Without interoperability, there is a risk that limited, fragmented or duplicative data is analysed and modelled to inform decisions which could lead to adverse outcomes.
- While improvements in connectivity have made possible the emergence of IoT sensors for the use cases explored in this report, **limited connectivity** continues to remain a barrier to scaling solutions and particularly in remote areas.
- **Lack of patient or longer term capital investment** is an inhibiting factor to the long term scaling of solutions. Many sensor projects are limited in duration and scope, and funding and monitoring activities usually stop once research is finished. In the case of disaster risk management, funding for technology tends to be prioritised towards response rather than mitigation - and therefore doesn't make adequate provisions to support longer term sustainability of technologies - which is critical for IoT sensors.
- While no Frontier Technologies pilots faced a direct challenge associated with **data privacy and ethics** there are clear risks that as IoT sensor solutions are scaled, they collect and make accessible private and sensitive information. This presents a barrier to safe scaling, even if there are no current major legal or regulatory barriers to implementation within ecosystems.

What are key enablers to testing and scaling IoT sensor technologies for social impact?

- Almost all Frontier Technologies pilots found that **government support** is crucial for both ensuring an enabling environment for piloting, and enabling scale. This is particularly the case where IoT sensors are implemented within public infrastructure (e.g. WASH, disaster risk management), but is also apparent in the private sector where changing policies and regulations can impact incentives for farmers to adopt technology.
- **Strong technical and contextual knowledge** has benefited pilots as a critical enabler to effective deployment. Existing knowledge supported pilots to customise solutions to local needs, and anticipate and plan for technical and contextual challenges before they emerged.
- **Service based business models:** The eWATER pilot, (as well as a number of other projects that have used sensors to enable sustainable and reliable access to water at an affordable price) has demonstrated the effectiveness of service based models, as a means of both meeting end user needs, and finding a way to sustainably fund the operation of sensor based solutions. Service based approaches aim to solve a whole problem for end users, rather than simply providing technology alone. For example, a service approach might aim to support users to optimise farming practices, and rather than simply providing products (e.g. a sensor network) will provide additional support to ensure the user need is actually met (e.g. tailored recommendations for optimisation practices based on sensor data, or training to use the solutions).
- **Translation of data for decision making** - if IoT sensor projects focus too heavily on the technology and not on the user needs for data, they risk failing to provide end users with relevant information, in a format that supports real-word decision making. By focusing on delivering effective translation of data, IoT sensor based solutions can achieve impact through providing users with the right level and type of information needed by users to make decisions at the right time.
- **Ease of use** is crucial in ensuring uptake of both sensors, and related solutions (e.g. dashboards and services providing data) by end users. **User-centred approaches to design and implementation** are critical for ensuring solutions are developed in a way that work for users within the contextual constraints they operate in, and ultimately help to meet their needs. Where sensors are designed to support decision making, projects benefit from working closely with end users in order to understand the key decisions they have to make and their incentives.
- **Engaging and raising awareness** of sensors and their benefits is key to ensuring that end users eventually adopt or are receptive to the solution. Frontier Technologies pilots observed that engaging community members helped both to overcome initial distrust of sensors, as well as persuade users of the benefits of adoption.

Where is the 'frontier' for further work (especially early stage innovation projects) testing IoT sensors for impact?

- Across the use cases explored through this research, a common thread was **the potential for AI, and particularly predictive analytics to unlock catalytic value** - if used effectively alongside sensor based solutions. In the case of WASH systems, natural hazards, or farming, AI shows potential for informing preventative interventions before something goes wrong (e.g. a WASH asset breaks, a disaster strikes, or inappropriate farming practice leads to soil erosion), through effective analysis of real time and historical sensor (and non-sensor) data. Testing the possibilities of AI remains at the cutting edge of IoT sensor implementation for impact.

- IoT sensors can have catalytic impact, when they support decision makers to make decisions based on comprehensive real time and historical data, that otherwise would not have been available. While sensors have enabled a revolution in access to information, **more work is required to deliver solutions that effectively translate data into actionable insights for decision makers**. As the example of the BIPAD Portal in Nepal demonstrates, **where sensors are already deployed within a given ecosystem, there's value in innovators focussing their efforts on building solutions which can effectively join-up this data, and translate it, based on the needs of decision makers.** A service, rather than product led approach towards implementation of sensors, can support effective translation, as well as open up new business models.
- **More IoT sensor projects need to start with a demand-led approach** - where technologists work with stakeholders, such as government service providers (e.g. Ministries responsible for the provision of clean water), in order to identify their needs and challenges, before identifying how IoT sensors, and associated solutions, can be used to address these needs, and improve service provision. To date, many sensor interventions have been supply rather than demand led - starting with a technical concept, rather than a clearly articulated policy priority, with underlying user needs.

References

Antony, A.P., Leith, K., Jolley, C., Lu, J., & Sweeney, D.J. (2020). A Review of Practice and Implementation of the Internet of Things (IoT) for Smallholder Agriculture. Sustainability, 12, 3750.

FAO. (2020). Agriculture 4.0 agricultural robotics and automated equipment for sustainable crop production.

GSMA. (2023). IoT for Development: Use cases delivering impact.

GSMA. (2022). Assessment of smart farming solutions for smallholders in low and middle-income countries.

GSMA. (2021). The role of digital and mobile in addressing climate change.

International Telecommunications Union / Cisco. (2016). Harnessing the Internet of Things for Global Development.

Kavitha, S., Sridevi S., Makam, P., Ghosh, D., Govindaraju, T., Asokan, S., & Sood, A. (2021). Highly Sensitive and Rapid Detection of Mercury in Water Using Functionalized Etched Fiber Bragg Grating Sensors. Sensors and Actuators B: Chemical. 333. 129550.

Mao, F., Clark, J., Buytaert, W., Krause, S. and Hannah, D. (2018). Water sensor network applications: Time to move beyond the technical?. Hydrological Processes. 32.

Nagel, C., Beach, J., Iribagiza, C., & Thomas, E. A. (2015). Evaluating cellular instrumentation on rural Handpumps to improve service delivery—A longitudinal study in rural Rwanda. Environmental Science & Technology, 49(24), 14292– 14300.

Ruckelshaus, M., Reguero, B.G., Arkema, K., Compeán, R.G., Weekes, K., Bailey, A., & Silver, J. (2020). Harnessing new data technologies for nature-based solutions in assessing and managing risk in coastal zones. International Journal of Disaster Risk Reduction. 51.

Rural Water Supply Network. (2010). Myths of the Rural Water Supply Sector. Rural Water Supply Network Perspectives. No. 4.

Smith School Water Programme. (2014). From rights to results in rural water services-evidence from Kyuso, Kenya Smith School Water Programme. Smith School Working Paper.

Thomson, P. (2020). Remote monitoring of rural water systems: A pathway to improved performance and sustainability?" Wiley Interdisciplinary Reviews: Water. 8.

UNDP. (2021). Precision agriculture for smallholder farmers

Vargas, A., Fuentes, M. & Marta, V. (2020). Challenges and Opportunities of the Internet of Things for Global Development to Achieve the United Nations Sustainable Development Goals.

Youth Innovation Lab. (2020). BIPAD for Decision making in Federal Nepal

PHOTO CREDIT: NISHANT GURUNG
Sensors installed in Chisapani, Nepal